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and

Oil-Shale Resources.

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Issue of Journal. The Journal appears in four parts per sessional volume, viz. in December, February, April and June. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

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Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of January, March, May or November as the case may be. Subsequent delivery may be too late for insertion.

The Library. In the full catalogue of the Library, published in our brochure of September, were included the titles of such papers in journals received as bear upon any subject within the purview of the Institution. Such titles are not included in the intermediate lists given in our several parts, where, as below, the journals received are acknowledged in single entries.

The attention of such of our members as are authors is directed to the absence of their works from the Library, (with some exceptions), and we shall be particularly thankful for gifts of treatises on special branches of technology, and for separate copies of papers contributed to other Institutions and to journals, either in past or future.

Additions to the Library.

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From R. R. Lewer.

Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1915–16. 8vo, *London*, 1916.

From Sir Boverton Redwood.

North of England Institute of Mining and Mechanical Engineers. Annual Report of the Council, and Accounts for Year 1915–1916; List of Council, Officers and Members for the year 1916–1917; Etc. 8vo, *Newcastle-on-Tyne*, 1917.

By Exchange.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Mr. G. W. Halse left for Persia in December.

Mr. Wilfred E. Guttentag has joined the Aeronautical Inspection Department.

Mr. W. H. Fordham has received a commission in the R.F.A.

Mr. T. P. Perrott has returned to England from Rumania.

Mr. G. P. Ashmore is still in Holland.

Mr. Alfred Harland is now at Singapore, having postponed his visit to Japan.

Addresses wanted: Messrs. J. H. Child and C. W. Hodsdon.

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EDITORIAL.

Co-ordination of Energies.

More than one moralist, in dealing with the all-absorbing topic of the War, has pointed out that, however lamentable the cause, one most beneficial effect has been the elicitation, if not the development, of some of the nobler elements of national character, dormant, or at least less perceptible, under the normal conditions of peace.

One such element, and that which perhaps concerns the Institution as such equally with, if not more than, some deeper considerations, is the suppression of minor jealousies and self-regarding tendencies in the hearty co-operation for the public good of men and women of the most strenuously competitive capacities. Many, whilst they would prefer spheres of utility to the maximum of their powers, are quite content, under existing conditions, with subordinate positions, inferior to what they could undertake, were there scope for such higher service from them. To paraphrase an excellent motto, they are willing to be wheel-greasers, although capable of driving the train, were not that function already otherwise allotted.

The same principle of self-abnegation comes into play when handling the many important problems forced upon our attention at the present juncture, into which considerations of the most diverse character enter as factors, the neglect of which would cause serious error in the conclusions reached. Specialisation, essential though it be to the maximum of efficiency, has a tendency to blind the specialist to the relative importance of the data obtainable from other lines of enquiry. Whilst amicably debating doubtful points with fellow-students of the same special topic, there is less readiness to admit the cogency, or even the relevancy, of arguments adduced by investigators of entirely different subjects, although collaterally bearing upon the ultimate solution of the problems under immediate discussion.

It is not enough that samples of petroleum collected by a traveller should be found by a chemist to be of a valuable description; that a geologist should pronounce in favour of the field as having a hopeful structure; that a mechanical engineer should design the plant for exploitation, a refiner for distillation and kindred processes; and civil and marine engineers the means

of access, transport, storage, &c. To the counsels of these, in co-operation, there is essential the addition of financial ability, which shall consolidate the data contributed by each into operations of commercial advantage, alike to producer and consumer. It is a most healthy sign of the times, that the necessity of this co-ordination of diverse abilities is being more and more generally recognised, and with it the corollary that the combination, in a single individual, of even two of the distinct rôles mentioned, is a guarantee of inferiority in one or the other, courting ultimate failure thereby: no man can be truly expert in two professions.

But, for perfect accord, equally in debate and decision, there must be fostered a spirit, not of self-suppression, by tacit acquiescence in untenable conclusions (which indeed would be a disingenuous evasion of the duty of counsellor), but of frank admission of the relevance of arguments from premisses on other sides of the subject. Few cases of practical importance are like mathematical lines, with but two diametrically-opposed aspects: the majority are polygons, often of very irregular dimension in sides and angles. The conservation of equilibrium requires a full recognition of this polygonal structure of every problem, notwithstanding the great difference in relative importance of the several aspects, none of which should be ignored in the adjustment of attention. In some cases the geological, the chemical, or one of the engineering elements is of very subordinate weight, whilst another assumes unusual proportions, but in every case financial and administrative abilities are indispensable: the latter in selection and control of staff and plant, the former in perspicacious grasp of all conditions, local or world-wide, that may exist or arise to promote or obstruct satisfactory execution of the complex operations involved. For this, harmonious co-ordination of scientific, technological and commercial capacities is an absolute essential, and this indeed is the *raison d'être* of this Institution.

W. H. Dalton, *Hon. Ed.*

Eighteenth General Meeting.

A meeting of the Institution of Petroleum Technologists was held at the house of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, 19th December, 1916, Professor John Cadman, C.M.G., D.Sc., M.Inst.C.E., (President), occupying the Chair.

The members of Council present were Messrs. Andrew Campbell, E. H. Cunningham Craig and Arthur W. Eastlake. Messages of regret for unavoidable absence were received from Dr. F. Mollwo Perkin and Sir Boverton Redwood.

The President announced that Mr. James, the author of the paper to be submitted to the meeting, had been summoned abroad, and had secured the kind offices of Mr. Cunningham Craig to read the paper. Having repeatedly met Mr. James, in Persia, Burma and Trinidad, he could testify to his capacities in the special subject of the evening, geological mapping.

Mr. Craig then read the following paper, illustrated by diagram drawings :—

Notes on the Subject of Geological Mapping.

By S. Lister James, F.G.S., *Member*.

Introduction.

In undertaking the introduction of this subject before the Institution the author feels a sense of considerable responsibility; for Geological Mapping is, on the scientific side, the first essential to the satisfactory development of the Petroleum Industry. It is, so to speak, the first letter in the alphabet of the industry.

It is therefore a subject of primary importance, which may be claimed as worthy of the combined consideration of this Institution.

The author ventures to hope that however lame the introduction may be, it may serve to rouse and stimulate discussion; while he further hopes that some hints may be given at least to the junior geologists of the Institution which will assist them in their work.

This is a subject the treatment of which requires for its theatre, not the four walls of a room in the heart of London, but, in turn, a commanding eminence in a desert land, with a view over hill and valley, and the dense enclosure of a tropical forest. There are some present who can supply these surroundings from a vivid recollection. The rest must be asked to have recourse to their imagination.

There is little in this paper for which the author can claim originality. The methods described and the remarks made are

based on the field-training so patiently given by one of the members of your Council some years ago, slightly developed in the meantime, and put to the test in different parts of the world under widely varying conditions of climate.

If the author can save some misapplication of energy by the use of inadequate or wrong methods, and help the young geologist who is beginning his career to learn from the commencement to read and record *facts*, and so reduce to a minimum the time spent on wild theorising and determined assertion of previous opinion, he will be well pleased.

A geological survey is a more or less intricate study in cause and effect, the results of which are of economic importance; and the more complete the geological history the more complete the data for determining the possibilities of oil production, and for choosing well sites in the most favourable positions.

A geological survey is now usually, and undoubtedly should always be, the first preliminary towards the development of a new oilfield, whether this term be applied to a small area or to a vast region. Were there no other factors to consider, the survey of the region which it is proposed to test should have reached an advanced stage of completion before even the commencement of drilling operations. Any departure from this rule, however unavoidable it may be, is to be deplored, since it necessarily increases the risk of failure and gambles heavily on probabilities. Test wells frequently incur very serious expenditure—in some cases far more than an adequate geological survey. It follows, therefore, that no effort should be spared to make the preliminary survey as reliable as possible. The reliability will depend primarily on the method of survey employed, or at any rate on the method in which the geologist has been trained. Prior to testing, not only should the stratigraphical sequence be determined, and the positions of flexures be ascertained, but other phenomena of the region should be recorded, such as faults, unconformities and overlaps. It sometimes happens that the existence of such important phenomena is not proved until development work has reached an advanced stage. In such cases considerable waste of money is liable to result from fruitless drilling. The original source of the oil should be ascertained, and the local types of structure which are likely to affect its accumulation. The only means of arriving at definite knowledge of such matters—as opposed to mere opinion—is by more or less extensive geological mapping. Scientific prospecting does not consist merely in the search for anticlines by the collection of dips (which may or may not be reliable) and it can be said without

hesitation that the sooner this is realised by all, the better for the industry.

With regard to the accumulation of oil, the fundamental fact is not that it necessarily collects only in domes and anticlines, but that it is lighter than water. The consequences of its lower gravity are that it is liable to be driven out gradually at the outcrop, or on encountering a barrier to be retained under pressure. This barrier may take the form of an impervious arch in the overlying beds, a fault plane, a plane of unconformability or of overlap, etc., while the oil-rock may be of lenticular form between two impermeable beds which merge up the dip. (See Diagrammatic Sections 6–10.)

Indeed, it is conceivable that, in rare instances, excessive lenticularity may minimise the effect of structure.

The work of the geological survey will consist in the construction of a map or a series of maps according to circumstances, with explanatory reports, sections, diagrams, stereograms and photographs as may be required. But to-night we are mainly concerned with maps, which form the basis for the other productions, and of which they are merely illustrative and explanatory. An accurate map is the first essential.

It is proposed to deal with the subject of this paper in the following order :

(1) To deal briefly with the scope of Petroleum Geology.

(2) To consider some of the essentials of a geological map.

(3) To consider what methods of fieldwork are calculated to give the best results.

(4) To draw attention to the important relations between topography and geology.

(5) To show how this knowledge may be applied to the mapping of ground covered with thick forest.

(6) To deal briefly with the rapid use of the trained eye in sketch mapping.

(7) Finally to make certain general observations in connection with the subject.

Scope of Petroleum Geology.

The work of the petroleum geologist is of wider scope than might be realised by the layman. There is, in fact, every gradation of work from the purely geological work of the pioneer prospector to that of the geological engineer. The geologist may cover the whole scope of the profession or specialise at the geological or the engineering end of the line according to early training, to natural bent, or to opportunities offered.

Thus as geological engineer he may be stationed on a developed field with duties connected solely with development such as keeping well records, correlating between wells, contouring oil-sands (or other recognisable horizons), selecting new locations, and advising on such matters as cementing.

Or the petroleum geologist may, on the other hand, be called upon to undertake such duties as—

(1) Geologically surveying an extensive region with a view to selecting from it favourable areas to be tested; (2) examining, that is mapping and reporting on an area under development; (3) reporting on a property, possibly of quite small extent, acquired without scientific advice, simply on the evidence of oil-shows.

It is fortunately not the purpose of this paper to discuss the balance of his moral obligations to client and investing public in such cases as the last mentioned.

It is with the work of the prospecting geologist that we are now chiefly concerned, that is to say, with mapping or the recording of surface evidence.

Some of the Essentials of a Geological Map.

Let us first consider some of the main points in a geological map. We can then pass on to the collection of data in the field. It seems hardly necessary to state that a geological map should be a coloured plan of the outcropping rocks, differentiating by means of these colours the different rock groups. Thus sandstone, clay, or limestone groups, etc., will be so distinguished. The use of colour is preferable to that of cross-hatching or stippling, as being more conspicuous. In fact, the aim of the geologist is to portray as clearly as possible and without bias, by means of colour, lines and signs, the relevant geological evidence collected, distinguishing where possible, between reliable and doubtful evidence, whether of dip or line of outcrop. Special prominence should be given to such matters as are of special significance by conspicuous colouring or other suitable means. It will be found advantageous to retain the use of colour, as far as possible, for purely geological evidence. Overcrowding of maps with details should be avoided, but evidence which cannot at the time be interpreted should be recorded. This will enable others to confirm the conclusions arrived at, to propose alternative explanations, or to call for additional evidence. Sharp distinction should be drawn between surmise and observed fact—apart from petty detail, of course. The former should only be introduced where evidence is lacking,

and then should always be based on a consideration of such evidence from other parts as may have any bearing on that in question. Where any doubt is entertained in regard to the course of an outcrop or other geological line, this should be indicated on the map, and it may be expressed by means of broken or dotted lines.

The scale to be employed will depend largely on the purpose of the survey. But multiplicity of scales is to be avoided, and in dealing with an extensive region it will be found highly advantageous to adopt standardisation to two or three scales in order that comparison between different areas may be made with greater facility. Either the 6-inch or the 8-inch scale will be found most suitable for detailed work of individual areas in ordinary circumstances, while the 1-inch scale is considered convenient for regional work and sketch mapping. Where the metric system is in vogue 1 : 10,000 is a useful scale for detail. Still smaller scales of course have to be used where the region to be shown is very large, and in such cases the convenient size of the map may be made the determining factor in the selection of scale. In dealing with an extensive region, it will be found of immense advantage to keep up to date a small scale general map recording the results of detailed work in different parts. This will show the inter-relation of the different areas mapped and indicate where to look for fresh evidence.

Though horizontal sections facilitate the reading of geological maps, especially for the layman, these latter should be *intelligible* without the necessity of their use. Geologists will realise the advantage of cultivating the facile reading of maps without dependence on sections.

The question of the general adoption of standard signs is one deserving of earnest consideration; while standardisation of such —as also of coloration and scales—should certainly be adopted by each separate geological staff. Systematisation in these respects obviously means saving of time, and the wider its adoption the greater the economy effected in respect of time and consequent cost.

Perhaps at no distant date we may have international conferences in every trade, industry and profession to settle, without personal or racial bias, the most suitable respective standards to be adopted. This however is a digression.

Fieldwork. If topographical maps are available the geologist's task is obviously much facilitated, provided they are reasonably accurate. When, however, no maps are obtainable, as is frequently the case, he must construct his own, spending as little time on

achieving great topographical accuracy and detail as need be, for accurate topographical maps are the work of a surveyor.

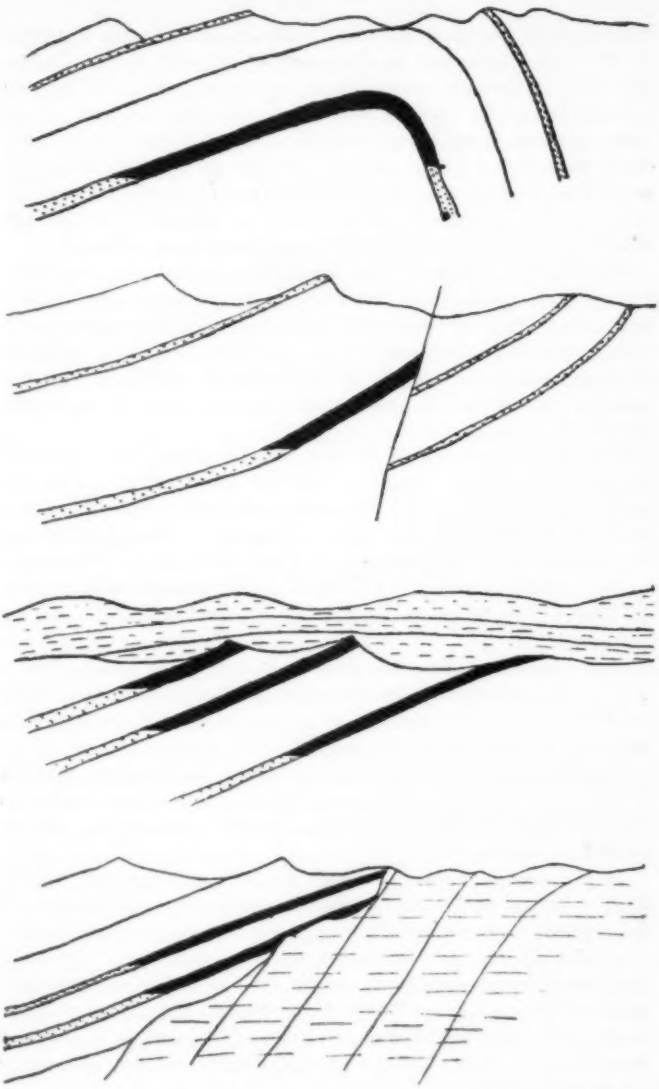
The reliability of the maps produced, i.e. the accurate recording of all relevant evidence, depends very largely upon the methods employed in fieldwork, as has already been stated. It is of course assumed that the geologist is thoroughly painstaking and persevering.

These methods have to be adapted to climatic and physical conditions—a matter to which we will presently give our attention. They must, in fact, be such as to produce under any conditions whatever a map recording all important geological evidence, direct and indirect. The geologist should learn as early as possible in his career to consider each exposure in relation to the whole area under examination, and not merely "on its own merits." He should see at once the continuity with or the discrepancy from other evidence. If the latter, what then is the cause of the discrepancy, in the light of further evidence? Without using a map this would be a much slower and more difficult matter. It is essential to his success that he should develop the ability to think not of single exposures, natural or artificial, but in lithological zones. Let him commence the examination of a region—or a small area, for that matter—by studying the most representative sections across the strike, whether on the coast, in road or stream, and dividing the strata into lithological groups.

He will find out the advantage of learning to read features so that any eccentricity in the topography due to faulting or other cause will catch his attention, and call for explanation by mapping. In other words, the existence of any physical feature which is not in agreement or continuity with the evidence already collected should arrest his observation. The policy of *commencing* the survey of a region by searching for one particular type of structure is not always the wisest procedure by any means, if indeed feasible. This particular type of structure (of course a simple and favourable one) may be wholly non-existent there.

It is ill-advised in the early part of a survey to linger long over difficulties, for a solution of these will probably be arrived at incidentally in the subsequent course of the work. But before leaving the ground the geologist should of course satisfy himself that he has all the data required, or all such as are obtainable, for the completion of his map and report, if, as is often the case, circumstances prevent his finishing these on the spot.

When dealing with a region of some extent, accuracy of mapping should be aimed at rather than extent of area mapped, so that,



FIGS. 6–9.—Structures favouring Conservation of Petroleum.

instead of overlooking important evidence, clues to the structure of the whole region will be discovered at an early stage. In this way lines of faulting, unconformity or overlap, etc., or it may be igneous intrusions may be traced from the commencement, and their economic importance made the subject of continuous study with the progress of the survey. On the other hand, if acreage were placed before accuracy in importance, it is possible that the whole of the preliminary survey might be completed without the determination of matters of vital importance being effected.

After having formed some preliminary impressions regarding the geological conditions prevailing in the region under survey, the geologist will probably subject to a detailed examination some part where oil-indications occur, enabling him to familiarise himself with the oil series, to determine its relations with the series above and below, and to ascertain the mode of occurrence of the oil.

During the course of a survey, theories should be formed as working hypotheses, agreeing with all the evidence collected, whilst that yet lacking for the confirmation of each theory should be realised and made the object of search. Obsession by any one theory, particularly in the early part of a survey, is a danger to be carefully avoided. The mind should always be kept open to fresh evidence or to alternative interpretations of evidence by others.

Whether undertaking the survey of a large or small area, a golden rule to follow is to commence with the easiest and most obvious part. The knowledge gained here will greatly help towards the solution of the more difficult portions.

So-called lack of evidence may be useful: for instance, a stretch of alluvium usually covers comparatively soft strata, owing to the facility with which these are denuded, and stream courses eroded to base-level.

In the examination of a small property it may well happen that evidence within its boundaries is wholly insufficient and incomplete. In fact, positive evidence may be entirely lacking —notably in the case of an expanse of alluvium. Evidence must therefore be sought out and recorded regardless of boundaries or, shall we say, by arrangement with neighbouring proprietors. Geological lines unfortunately have no respect for property boundaries, a fact not always sufficiently realised—especially by rival companies!

To show an anticlinal axis merely on the evidence of opposing dips is an entirely unjustifiable procedure; but a common failing,

implying a fault. Quite different series showing opposing dips may in fact be brought in contact by faulting.

Again, in the case of a highly inclined monocline, strata (especially those of soft nature) may be terminally curved so as to show an apparent reversal of dip. Where a consideration of the general evidence leaves no doubt as to the continuation of the monocline, such dips are preferably not recorded, or if shown ought to be qualified by a query.

Further, current-bedding may give the impression of an anticline if opposing dips are considered necessarily to indicate the presence of such. High angles of such are sometimes present in beds but slightly affected by tectonic movement, and even in thin shaly alternations of sand and clay, which one might expect to be free from current bedding. In the mapping of developed areas, greater attention will of course be paid to detail, and closer topographical accuracy secured. Where the

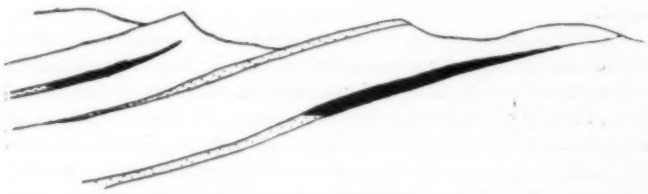


FIG. 10.—Conservation of Oil by Lenticularity.

structure is anticlinal, the pitch of the fold should, if possible, be determined with accuracy. Intermediate horizons may be mapped locally with advantage to portray local subordinate structure, or to show the correlation of different wells by their position with reference to an index horizon, key-rock as it is called in the United States.

In oil geology the actual determination of the age of a series is not considered to be of primary importance, local classification being sufficient for practical purposes. Palæontology may do considerable service in *supplementing* mapping, but more harm than good by *supplanting* it. Its value in correlating self-contained areas, isolated by newer unconformable deposits, will be obvious, if the series be zoned throughout at its outcrop.

Elaborate mapping in the middle of a group, without any special object such as the correlation of different wells or the portrayal of local structure, is to be avoided. Mapping should rather be

kept to the vicinity of group-boundaries to prove faults, unconformities or overlaps.

In the case of a highly complicated and obscure region, the first observer may, through lack of time or insufficient experience, fail to solve all its important problems. But the accurate and unbiased recording of evidence will at any rate greatly facilitate the *ultimate* correct interpretation of the full geological history, which should be the preliminary to selection of sites for test wells.

Equipment Instruments, etc.

The simplest and most portable instruments are the most suitable —such in fact as require the smallest fraction of time for manipulation. A field outfit, adequate for ordinary purposes, may be enumerated as follows:—Map-case, prismatic compass, hand compass and clinometer combined, mapping paper, hammer (sometimes cutlass is more useful), tape-line (or chain), protractor, lens, and a few coloured pencils; also for occasional use, pocket aneroid and Abney level. A few notes are appended on these articles of equipment.

Leather map-case (12 in. × 9 in.) similar to that used by the British Geological Survey. As a provision against warping in hot climates, it is well to have the case stiffened with a foundation of compressed fibre, thereby obviating much trouble from this cause. The slight increase in weight is more than compensated for. In the underside of the flap separate sockets for about four pencils may be provided, while another may be made to receive a "finger" rubber, unless the lead pencil itself be armed with an eraser, which is a still better arrangement. Again, another socket under the maps may contain the protractor, if so desired. In countries where shirtsleeves are the rule, at any rate, it is found an advantage to carry these etceteras in the map-case itself. A waterproof bag will be found necessary to protect the map-case in wet weather. In order fully to appreciate the indispensable nature of the map-case, the geologist needs to have commenced his fieldwork without one; the subsequent provision of this requisite is like the gift of spectacles to a half-blind man.

Hand compass and clinometer combined. The box variety of the combined instrument is preferred to the ordinary sort by the author, on account of the greater length of surface for measurement, the greater protection afforded to the glass, and the more satisfactory needle brake. In very hot climates splitting of the wood, consequent on expansion of the metal should be provided against by rubber packing or otherwise. The instrument is carried in a leather wallet attached to the belt.

Hammer or cutlass. This needs no special description. It should be of medium weight, and it may be carried very conveniently by passing the handle through a stiff leather loop sewn on to the belt. A cutlass, or a Mexican machete, is often far more useful in dealing with argillaceous strata, as it enables the bedding planes to be cleaned off with much greater facility.

A pocket lens is sometimes very useful, but is regarded as being ordinarily one of the least essential items of equipment.

An ivory protractor graduated with 6-inch scale, or other in use; also table of depths and thicknesses on the back.

Mapping paper. The author favours the use of sectional drawing paper, the squares of which bear a simple relation to the scale in use. Where distances are merely paced or estimated, its use eliminates one of the two sources of error. Moreover, the squares are of assistance in the correct recording of direction of dip. Admittedly, it is well to be able to judge distance and angle by eye, on paper as well on the ground; but the author opines that the less *ultimate* reliance is placed on such a variable measuring "instrument" as the human eye the better.

The Abney level, besides being useful in the determination of heights, may be employed for the accurate reading of dip-slopes, and for determining the pitch of an anticline by taking observations between two points on the same horizon at the crest.

A plane table is used by some, and it may perhaps give greater *topographical* accuracy; but any instrument which requires setting up, and which in any way hinders the geologist from the rapid *following* of horizons must be detrimental to quick and accurate mapping. For fixing accurately the position of a few prominent points as a preliminary to the geological survey, it may conceivably be made most useful, but not ordinarily for the filling in of geological detail as it should be done. In the author's opinion, nothing can satisfactorily take the place of a map-case and compass.

Structural accuracy should surely be the aim of the geologist, and this should certainly not be sacrificed to topographical accuracy.

Methods of mapping. In the highly instructive task of carrying out the geological survey of a desert country, we have bare rock to deal with, where we can study minutely to our heart's content, and without drawing on our own imagination or on that of other people, the conditions of deposition and of earth-movement; where in fact every word of the geological history of the region is written large, though it may not always be easy to decipher.

In such a country the geologist with a trained eye may read much of this history in a rapid traverse; when he will be able to

form working hypotheses to guide his subsequent detailed work, and will fill his mind with ideas to be developed or eradicated with the accumulation of further evidence. It is in such country that he is best able to learn the possibilities in rock-folding; the effect of denudation on the course of outcrop, varying with angle of dip; the significance of lateral variation, of terminal curvature, and of current-bedding, and the vagaries of contemporaneous erosion.

It is essential in a homogeneous alternating series, as most oil series are, at least in the author's experience, actually to trace with care individual horizons. However laborious this may appear to be, it is a habit which, it may be emphatically affirmed, should be cultivated from the commencement by every geologist. It is in fact the secret of success. Only in this manner can faults be proved definitely and traced, only in this way can slight unconformities and overlaps be demonstrated beyond question.

To most of you no doubt this is quite evident; but it is a fact which is *not* recognised by every one of the profession, with the result that much time is wasted in discussing mere surmises when facts can be demonstrated often so easily. Furthermore, it is by following individual beds that one learns the significance of lateral variation and develops the ability to read physical features, a matter of the utmost importance when actual exposures are lacking, as we shall see in our further consideration of the subject. It is in this way that one learns to recognise and discount the false evidence of current-bedding, terminal curvature, contemporaneous erosion, etc. As is well known, the ability of the field geologist—i.e. the reliability and rapidity of his work—depends largely on the training of the eye, or on the power to read the geological significance of physical features. It is by working on these methods that he effects this training.

Let us now go a little more fully into this question of detailed mapping. Let us commence as beginners, with an imaginary area, which is diagrammatic in its simplicity. Let us suppose it is an elongated dome. We first proceed to some suitable high point whence we can get an extensive general view of our area. We see, let us say, bed after bed of sandstone, alternating with clays, forming excellent scarps, and dip-slopes. The structure is absolutely clear to us; we can see these beds successively swinging over the crest at either end of the dome and joining up on the other flank. But how are we to embody in the form of a map the essentials of what we see before us? To record a number of dips all over the area will be wholly inadequate; while, on the other hand, to

trace every sandstone band that we see is entirely unnecessary and out of the question as employing too much time. But let us select for mapping a few of the most prominent beds at vertical intervals of perhaps 200–300 ft., extending from near the crest to some distance down the flank, according to the steepness of dip. Now we should make a point of *keeping* to these horizons, and not to be constantly changing to fresh ones, as there is a strong tendency in the beginner to do. Where however one bed becomes obscured for a space, it is justifiable—in fact advisable—to trace a neighbouring horizon until the original one can be picked up again. Such a course will guard against the possibility of overlooking a fault. It is much easier to follow the course of a bed than to put it on paper. But the mapping of a bed merely consists in surveying two lines, the one at the base of the bed, the other at its junction with the overlying stratum. Where the bed occurs in a scarp face, these lines will obviously be close together; while with a dip-slope they will diverge, the upper one being drawn at the foot of the dip-slope. These remarks apply equally to a band a foot thick as to a thick group. A base line is measured, and the position of a number of the most conspicuous objects fixed by triangulation to form the foundation of the map—they may be hilltops, trees, etc. These points are of course selected largely on the suitability of their position in respect to the beds that are to be mapped. With a few of such points on his otherwise blank mapping paper, the geologist may proceed to his starting point on one of the beds selected. Here he fixes his position, and proceeds to follow the bed, mapping it as he goes with hand compass, or merely by reference to the points already on his map, or by reading ahead some distance to another point on the same bed with his prismatic, plotting the line as a guide, and judging distance as he goes. From time to time his position is fixed, preferably at prominent points on the bed, by prismatic bearings on the original fixed points. Obviously the two lines representing the base and top of the bed respectively, must not meet—except in the case of a lenticular bed. It is one of the best tests of the accuracy of an intricate map to see that in the tortuous line of outcrop the base of the bed has not been connected with the top in error. Here the use of colour is immediately apparent.

If the beginner grasps these simple notes, and applies the knowledge honestly and perseveringly, he will find that with the progress of his map he is demonstrating facts. Let him be slow and thorough to commence with, for accuracy is of immeasurably greater importance than speed. A few days' extra work—a few

weeks or months if necessary—represent a very small premium on the insurance of the conclusive testing of an area.

It is frequently of great assistance to sketch in from a distance the bed to be traced, before undertaking its more precise mapping, as it often happens that the course of outcrop is then more obvious than from close at hand.

Pits or trenches may be found necessary to supplement mapping, but *not* as substitutes. To excavate before the completion of the map—of surface evidence—is ordinarily to run the risk of duplicating the evidence of natural exposures or of obtaining costly evidence where it is really not required. The most prominent beds should of course be selected for mapping—for instance a thick sandstone in preference to a thin fossil band, though the latter may serve on occasion for identifying the former.

Mention should here be made of the system of underground contouring of oilsands or other recognisable horizons, which is so largely employed in the United States. This most useful means of portraying underground structure might, in the author's view, be further improved by the use of various colours to distinguish different contour intervals. This would greatly facilitate the rapid reading of such maps.

Where a homogeneous alternating series is concerned, blessed with several oilsands not far apart, and with no trustworthy index horizon, the correct correlation between wells, and consequently also the drawing of subterranean contours, may be a matter attended with considerable difficulty.

Relations between Topography and Geology.

Let us consider briefly *the relations between topography and geology* before passing on to the geological survey of tropical forest land.

Working in desert conditions, the geologist may notice—

(1) Distinctive colouring of different rock groups. In some parts this is very helpful. The author recalls an instance where, though new to the country, he was able to read the structure correctly from a distance which must have been ten or fifteen miles—so clear was the colouring.

(2) Another thing will also be apparent if he is able to get a general view from some eminence. He will see that each rock group develops its own type of country. Conversely, it may be reasoned from this (where exposures are lacking) that passage from one type of topography to another indicates that a lithological boundary line has been crossed. The geologist will soon become

so well acquainted with these different types that he can sketch-map with great rapidity and considerable accuracy as soon as he has acquainted himself with the sequence and the type of structure prevalent.

With the assistance of good topographical maps, and a general knowledge of the geology of the country, one can tentatively project geological lines with a fair degree of certainty, and to some extent read the structure of areas never visited by means of the contours. This is not recommended as a reliable method of geological surveying, but an intelligent study of the topographical map before visiting the ground may be found to assist materially in forming a programme of fieldwork. Moreover, the intimate study of *an uncontoured* map will often yield useful geological information.

The harder the members of a series, the straighter the drainage, conforming with the strike; the softer, the more serpentine the stream-courses. Strike lines are thus often indicated on a map by stream-courses; and also by roads. A group boundary, between clays and sandstones, for instance, may sometimes be detected by a marked difference in the course of the road. Thus sharp turns suggest avoidance or oblique ascent of ridges of sandstone or other resistant strata.

Mapping in Forest Land.

We will now pass on to the consideration of mapping in tropical forest land. Let us suppose that the geologist finds himself confronted with the problem of reporting on lands in the depth of a tropical forest, where not only are natural exposures few and far between, and when met with perhaps of doubtful value, but where the woods are so thick as to necessitate hewing his way almost every step; where he considers himself unusually fortunate if he can see at all clearly for more than 100 feet or so. Truly it needs a stout heart in a beginner to tackle such ground, and to maintain his energy and enthusiasm. In fact, it is asking far too much of the average novice to give him such ground to map. The reward of such parsimony is liable to be unreliable maps at the expense of an unnecessary amount of time and money.

How is it possible to make a satisfactory geological survey of such country—or rather, what method will give the best results at a reasonable cost? If there are contoured maps the task is of course immensely simplified, but let us suppose that such do not exist. The geologist will be well advised, before settling down to the survey of the actual ground delineated, to make a thorough

study of such sections as exist anywhere near—whether along coast, river or road. This work may take him many miles from his own area, and will possibly occupy a considerable amount of time; but there will probably be a saving of time in the end, while the knowledge so gained will be invaluable to him in dealing with the more obscure ground. In his intimate study of such sections, he should pay special attention to (1) the distribution of hard and soft beds; (2) the presence and character of any hard bands, concretions, fossils, or pebbles which may characterise any group or the series as a whole; (3) the physical features developed. It is especially important to take note of any hard material, for two or three small distinctive nodules may do great service in the identification of a group where exposures are lacking. Argillaceous strata are seldom, according to the author's experience, entirely without hard concretions or nodules in some sort or other; and where two soft groups are brought in contact without exposure, these hard elements may form the only means of differentiation; and the same with the occurrence or absence of fossils.

Having made a fairly intimate examination of the principal existing sections, the geological surveyor will have equipped himself with some almost indispensable knowledge for the prosecution of his survey. If the geology be simple, he may have established the stratigraphical sequence beyond doubt; but, on the other hand, if it is complicated, the true relations between the groups represented may not be at all clear. He will now have to consider the topography formed by these groups. In the course of examining and mapping the sections he will have noted any beds which, by reason of their greater hardness, unusual thickness, or isolated position, form prominent features. Any such situated near the group boundary will be especially useful to follow, in that they will indicate the nature of this boundary by their parallelism with it or their discordancy—presuming that the dip remains constant. Under normal conditions, where neither desert bareness nor luxuriant tropical growth prevails, but the physical features are plainly visible, reliable mapping may be carried out with the help of but few exposures. From this stage pass on to that of tropical forest land such as we have been considering, where the physical features are less definite owing to a thicker covering of soil and the protective effect of the vegetation, and where the geologist who has learnt to depend so much on eye-training finds himself veritably blindfolded by the thick forest growth. So handicapped is he that he has practically to "feel his way" in parts. Most will admit that mapping under such conditions

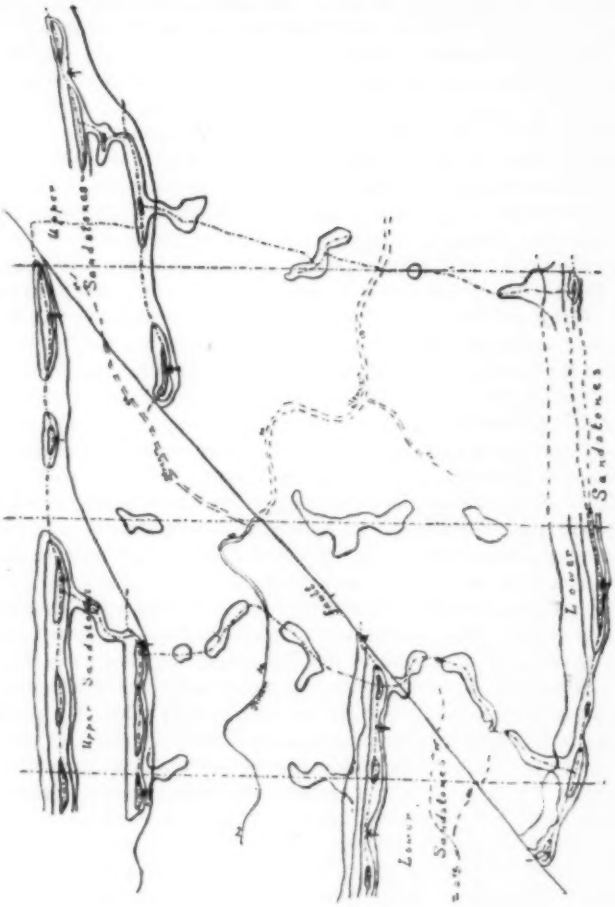


FIG. 11.—Diagram Geological Map, showing use of Contour Traverses to determine Structure in thick forest with few exposures. Traverses shown by broken lines — · — · —. Note unconformity, overlap, fault and difference between rock and clay features.

is not easy; but it is possible, even in complex structure, if undertaken in the right way. But it hardly need be added that perseverance and persistent optimism are essential to success.

The following simple method (see Fig. 11) has been employed by the author and former colleagues with a certain measure of success in elucidating complicated structure under such conditions, where other methods had achieved less definite results. Straight lines are cut through the forest, preferably at right angles to the general strike. These are surveyed accurately, distances being marked at frequent intervals (say 300 feet) by means of rough posts blazed at the upper end so that the distance may be pencilled on. It is surprising how long these figures will remain legible; the author thinks he is correct in saying that in exceptional cases they endure as long as two years if written firmly. The nature of the ground so traversed is indicated by rough contour lines (or "form" lines), posts being placed on the summit of any ridges of importance, and the position in the line indicated thereon. All this preliminary work may well be done by a surveyor, under the direction of a geologist. Such lines may ordinarily be placed at intervals of half a mile, but the interval will vary with local requirements and with the accuracy with which the geologist can complete the map. Thus provided with a plan of accurately surveyed lines, showing by means of "form" or contour lines the character of the ground in different parts of the area, the geologist has a sound basis for his survey, whatever the nature of the country. The most important hill features are now traced by means of "contour traverses" starting from known positions on these lines. Let us suppose that a clay series and an alternating series of sandstones and clays are represented. The clay ground may be left largely to map itself, and attention be devoted almost entirely to the sandstones, the features of which will usually be readily distinguishable by reason of their greater sharpness, prominence and regularity, apart from the nature of the soil. It will be advisable to commence with a prominent feature near the junction with the clay series. Starting at a suitable point on one of the lines, the geologist maps his way along this feature, indicating its form and direction as he goes, by means of sketched contour lines. On reaching the summit of the hill he will probably find that it now follows the strike, or the direction of the strike will be apparent from the contours. The contour traverse is then continued along the strike, or, if this leads down to low ground, it is better to keep to the highest ground by picking up the next strike feature, subsequently returning to the original strike line

if the feature be strong enough to warrant it. To descend to low ground where such is avoidable without going entirely contrary to the strike is to run the risk of wasting time cutting and mapping one's way over alluvium, only to find on regaining the "solid" beyond that a complete and unexplained change has taken place *somewhere* in the interim. The advantage of keeping to the highest ground will be seen when it is realised that this is ordinarily formed by the *hardest* rocks, which will therefore be the surest indicators of strike. The contour traverse will follow a zigzag or straight course according to whether—(1) the bed is immediately overlain by soft strata, or (2) contains continuous hard bands, on the one hand; while a zigzag character will be due (*a*) to succeeding sandstones above or below the first or (*b*) to lack of continuity in the concretionary bands at any one horizon. The amount of interval between the contours is not one of primary importance; but the slightest eminences from the main feature should be indicated, as it is sometimes found that where strike ridges are not prominent a succession of high points clearly indicates the strike. It will be recognised that the advantage of these contour traverses over attempting to map geological lines direct lies in the greater facility of returning to the same horizon, after once leaving the feature and losing it from sight. Where the dip is comparatively gentle, it is usually easy to distinguish between dip-slope and scarp; but with the steepening of dip the difficulty naturally increases, while this difficulty is further enhanced by poor consolidation of the rock. In two adjoining series a firm arenaceous and an argillaceous the boundary may be discerned from a topographical map by the contours—or, in other words, by the direction and form of the features as indicated on the map.

It will be observed that the drainage system of the clay belt will be dominated by the more resistant series.

Diagram (6) is in illustration of the methods described in this section.

Sketch Mapping.

Having been trained to detailed mapping on the 6-inch or 8-inch scale, the geologist should have acquired the ability for rapid grasp of essentials. He will then be able to adopt more rapid methods for preliminary work. Such work, which is the basis for detailed geological surveying, has to be adapted more to local conditions. Thus traverses may be made—to mention a few ways—on foot, horseback, by camel, by boat, or rarely perhaps by motor-car. Pacing may be adopted in the first instance,

while for other methods a time scale may sometimes be very useful. The adoption of rapid methods suitable to local conditions will however only entail a little thought on the part of the geologist, who has learnt to *see* the essential data to be collected.

With rapid development in every branch of knowledge and the means of acquisition thereof, topographical and geological mapping are likely to be affected. There are parts of the world in which rapid preliminary work could no doubt be carried out advantageously from the air, by aeroplane and camera by a trained geologist familiar with the series represented and with the types of structure prevailing. The distortion of scale by camera would of course require to be rectified by compensating lens or other means for the production of topographically accurate maps.

Perhaps it will be considered a pardonable offence and not wholly irrelevant to say a word with regard to differing conclusions of geologists. For unfortunately geologists do not always agree, and we may acknowledge the fact without necessarily repeating what we may have said about each other! A friendly rivalry will be acknowledged as a healthy state of affairs, providing differences are settled in the field. But in denying the accuracy of another's map, should not the second observer, for his own sake, submit in support a map of sufficiently large scale to show clearly where the first has erred? A mere verbal denial, unless very explicit, counts for little or nothing; does not merit credence, and is a waste of time. The real desire of all is surely to arrive at accurate knowledge, and towards this end each successive observer should be able to contribute some fresh facts. By unsupported verbal denial of previous conclusions a minus contribution is made. The recording of a fresh piece of evidence may bring new light to bear on a problem and may disprove the conclusions of previous observers. Therefore the author holds that geological conclusions should always be in a state of suspension rather than precipitation—to borrow chemical terms. In other words, the geologist should never be so positive in his conclusions as to be deaf and blind to the arguments of fresh evidence whether adduced by himself or others. In fact the consequences of every item of evidence should be weighed in turn as they come to light. It is to be hoped that the time is nearly past when the Company Promoter risked his own money (and possibly also that of other people) by hurriedly acquiring land to which he took a fancy and then—and not till then—commissioning a geologist to report on the property and locate wells; perhaps subsequently blaming him if his "forlorn hope" tests proved unsuccessful. Precision

of mapping, and therefore of locations, depends on abundance or paucity, clearness or obscurity of evidence. Where one test well may suffice in simple and obvious structure, two or three at least may be necessary where it is complicated and obscure. The drawing of sections across unmapped ground is a very hazardous proceeding, except perhaps where structure is very simple and obvious. Even then such a course should certainly be avoided by the beginner, whose eye is not yet trained to detect subtle irregularities. With regard to the consideration of small areas, it may be said that to take one small property from a geological map can be aptly compared with abstracting one small component piece from a complicated picture puzzle. It may possibly be self-contained, but on the other hand it is just as likely, or more so, to be wholly unintelligible as a separate entity; for geological lines do not necessarily conform with estate boundaries! As the geologist extends his experience he finds that every new region visited has its own characteristics, stratigraphical and structural, while having something in common with others previously examined —and the same with every small area. The importance of grasping the main essentials at an early stage in the survey is obvious, and the facility with which these are grasped depends very largely on the methods in which the geologist has been trained. The methods herein described can claim the demonstration of facts and the training of the eye.

In conclusion, the author would like to record his indebtedness to Mr. Dalton for suggestions kindly given during the preparation of this article.

DISCUSSION.

The President then read, to open the discussion, a communication from **Sir Boverton Redwood**, who had been most reluctantly compelled to be absent, for the first time, from a meeting of the Institution, health-considerations being paramount in view of the extreme importance of his arduous work in State interests, notwithstanding the pressure of which he had found time to write as follows:—

The author of this thoughtful and valuable paper modestly disclaims originality of treatment of the subject dealt with, but I venture to say that he has nevertheless laid before us certain considerations which, though in a sense obvious, have not before been effectively emphasised.

The importance of what the author happily terms the first letter of the alphabet of the industry, is becoming better recognised every year, but unfortunately there are still some in positions of authority and control who can more readily be induced to spend £5,000 on a test-well than one-fifth of that sum on preliminary geological work.

The value of the procedure advocated by the author, lies in the fact that the suggestions made are based upon varied practical experience in the field, followed up by tests which have proved the soundness of the conclusions arrived at.

I chiefly admire what strikes me as the key-note of the communication, viz., the injunction to keep an open mind. I suppose every geologist will admit that geology is not what one would select as a type of the exact sciences, and every self-respecting geologist should welcome further evidence which may throw light upon doubtful points, but I am fully in sympathy with the author in deprecating the sort of destructive criticism of previous work which one occasionally meets with.

The President then remarked that petroleum geologists were sometimes apt to trespass upon phases of the great problems of petroleum technology which were really outside of the province of geology. The Institution was particularly fortunate in having a contribution upon the elementary procedure in the geological survey of an oil-territory, a contribution set out in a very simple and clear manner. The Institution was indebted to Mr. James for the great care devoted to the preparation of the paper. There were one or two points which were well worth reading and re-reading; for instance, the author's statement that scientific prospecting did not consist merely in a search for anticlines by the collection of dips, etc.

Again, the latter part of the paragraph in which Mr. James had indicated the procedure in connection with geological mapping might, he thought, be taken as a text by all young geologists, and it was a section that was worth printing in very bold type.

There was another point upon which he would like particularly to dwell, the reference to the important subject of topographical survey. The geologist's career was frequently much limited by the absence of knowledge of the principles of topographical surveying. He thought that a geologist's training should include the fundamental principles of surveying, so that he could if necessary make his own topographical map or more readily undertake mapping, even the sketch, at least a map sketch as referred to by Mr. James. The average petroleum geologist had, in countries where no available maps existed, to commence making one for himself, not altogether a simple matter without the necessary training in topo-

graphical surveying. The paper lent itself to questions from junior members, and he was sure that Mr. Cunningham Craig would be very glad to answer any which might be put. There were, of course, points which would appeal to those members of the profession who had had great experience in the subject, and he therefore proposed to call upon Mr. Dalton to give the Institution the benefit of his views on the paper.

Mr. W. H. Dalton considered that Mr. James had shown an admirable sense of proportion and balance in cutting down within the limits of a paper a subject that would fill a large text-book. Besides the several instruments mentioned, there was one to which Mr. James had not referred. This instrument was of very elaborate construction, and needed great care to keep it in good order; at the same time it was extremely portable and cost nothing: it served for roughly estimating distances in the absence of better means. The thumb held up at arm's length, and viewed by each eye alternately, would appear to traverse a width of the landscape, estimable with fair approximation by its relation to that between any two points (A, B, in Fig. 12,) of known position within the same range of view. With the measured distance between the eyes, and the length from the bridge of the nose to the thumb, the similar triangle from the thumb to either of the distant points would give the observer's distance therefrom within sufficiently close limits of accuracy. As a rough average, the distance would be eleven to twelve times that apparently traversed by the thumb. It was not necessary that the region should be either desert or prairie for the use of this method.

FIG. 12.—Method of Rough Estimation of Distances.

Mr. V. C. Illing, speaking as a visitor, said that the subject of the paper was one in which he was greatly interested, and the author was to be congratulated on the clear way in which he had dealt with it. The question of geological mapping was a very difficult one to deal with adequately; some of the factors would require a

large volume for their exposition, involving as they did the fundamental principles of geology. Before touching upon matters on which perhaps there might be differences of opinion, he would like to emphasise further a few points in the paper.

Firstly, with regard to the question of surveying, it was not always realised by those who sent out geologists, how seriously the latter were handicapped, if, in addition to their own work, which was exacting enough in itself, they had also to construct their own topographical maps. The speaker considered that in all cases of exploratory work, a surveyor should accompany the geologist, acting as his right-hand man, and enabling him to concentrate his attention on the geology of the region covered. Another point which deserved consideration, was the accordance of greater freedom of action to the geological investigator. He knew of cases where young geologists were relegated to work in virgin forest country, and their requests for opportunities to visit neighbouring coastal regions with invaluable natural sections were regarded suspiciously as so much wasted labour. It is for the geologist to decide where to look for his evidence: a fact noted in one locality might become the key to a knotty problem in a region 50 miles away.

He was pleased to find that Mr. James had laid great stress upon the actual proof of anticlines by mapping, and by mapping only. In the application of geological methods, insufficient training was sometimes displayed. Cases were unfortunately still prevalent of investigators indulging in a process of dip-hunting, the happy discovery of two dips in opposite directions being regarded as sufficient proof of an anticline.

He would have wished that the author had drawn more attention to the subject of stratum-contouring, for there was far too little use made of this method of structure-representation. Not only was this a question of the mere representation of structure, but also the application of this method, especially in cases of gently-dipping beds, revealed to the geologist unsuspected details of structure, and in other cases gave the solution to baffling fault problems. The American investigators had made free use of this graphical method of structure-representation, and perhaps the recent paper by Professor Fearnsides on the Barnsley Coal-Seam was a happy prelude to its wider adoption among English geologists.

The speaker could not entirely agree with the author's remarks in the section on Topography and Geology. Into a very small space an attempt had been made to cram a very large subject; such an attempt was foredoomed to failure, and was sure to involve the writer in statements appearing at best crude or even worse. Thus,

for instance, the speaker could not follow the statement that the straightness of the drainage lines depends on the hardness of the rocks, for it was not so much a mere question of hardness as of structure (especially of dip) and of geomorphology. It was almost a platitude to say that the topographical features follow the geological outcrops; the complexity of the latter in a dissected region varied as the co-tangent of the angle of dip. Thus, in a region of very gentle dips, the outcrop was generally complex, and the streams were irregular. In addition, the various stages in drainage development, i.e. those of youth, maturity, and old age, each showed a relationship to rock structure and hardness different in degree and often in kind.

With reference to the mapping of densely forested areas, the speaker had been over some of the ground mapped on these lines, and could pay a tribute to its thoroughness. The method of course did not involve any new principle—in all densely forested country a map which made any pretence of being more than sketchy must have been based on some principle of a double series of cut tracks or of actual clearance, while the depth of weathering in tropical regions rendered the digging of a certain number of pits for geological evidence a matter of advisability, if not of necessity, in all but the most favourable localities.

However, it was not so much the speaker's purpose to emphasise or criticise points in the paper as to call attention to other facts. The system of stratum-contouring in all favourable regions should be supplemented by a system of isochore lines (lines of equal interval from certain datum horizons to the oil-bearing sands), from surface evidence when that is obtainable, but still more from the results of drilling. For it was not legitimate to assume that the surface structures are faithfully imitated at greater depths—the prevalent distribution of unconformities and disconformities in oil-bearing regions was sufficiently well known to put the geologist on his guard against such an assumption. In addition, it would often be found desirable to introduce a method of representing the lateral variations in thickness of the important beds. These could be graphically represented on the same system as the isochore lines, and it had been suggested that these lines of equal thickness of a given group of beds be termed isopachytes. Such a series of lines would indicate the regions where the beds were thicker and, therefore, probably more coarse, i.e. zones where, under favourable conditions of structure, oil might be looked for with the greatest probability of favourable results.

Again, there was the vital question of the identification of certain

horizons. The technical application was not so much concerned with the actual geological age as with the correlation of horizons, known to be petroliferous in neighbouring regions, and with the tracing of certain horizons during mapping. Unfortunately, in many oil regions, palæontology did not render much aid, and identification of strata was a matter of boundary tracing and comparison of physical characteristics. Petrographical methods could, however, be applied with a great measure of success in the correlation of sediments over limited areas. Samples from the sandy horizons should be disintegrated, panned, and then treated with heavy liquids, such as bromoform or mercuric iodide solution of sp.gr. 2·8. The heavier minerals thus separated from the lighter quartz and felspars could, after electromagnetic separation, be microscopically examined and identified. It was found that these heavy minerals did not occur indiscriminately in all sandstones, but that while a few minerals like zircon, ilmenite, tourmaline, etc., were widespread, others like garnet, andalusite, kyanite, staurolite, hornblende, epidote, and magnetite, were only abundant in certain horizons within definite areas. Usually a particular sandstone was characterised by a combination of several of these typical heavy minerals. The recent work of British geologists had shown that the sands of the Jurassic, Cretaceous, and Tertiary formations in England could be identified and differentiated in the laboratory by these mineral analyses. The speaker had used the same method in differentiating the horizons of the Tertiary beds in S.W. Trinidad, and the results had proved equally encouraging.

It could not be too strongly urged that this method in no way supplanted the evidence of palæontology, neither was it adapted for widespread correlation. Sometimes experience showed that it would hold good over several hundred miles of outcrop, but in other cases variations appeared in much smaller distances, depending of course upon the conditions of sedimentation. In addition to this broad classification it would appear that particular sandstone beds within an arenaceous formation were often characterised by certain peculiar minor variations in the particular type of residue, and these variations hold good within the limit of a small field. The adaptation of these petrographic methods to the geologist's use led one further to the consideration of the utilisation of drilling records. The system, still unhappily prevalent, of leaving the identification of the beds in the borehole to the peculiar nomenclature of the driller could not be too strongly condemned. The source of invaluable information was thus often rendered useless, and even dangerous to the unwary geologist. Many logs are even

a delusion and a snare. This was not a condemnation of the work of the driller, but rather of the system which allocated the work to the wrong individual.

The map of the geological outcrops produced by the field geologist was an approximation, more or less exact, according to the methods and insight applied and the difficulties encountered. It ought to be supplemented by the evidence afforded by drilling, and the geologist who had in hand the collection of this evidence was entrusted with a task just as important as that of the original investigator, and calling for the same scientific treatment. It was the same process of geological mapping being continued, but now by evidence obtained underground. The collection of samples from wells should be developed much more systematically, and the investigation of these samples by heavy-mineral analysis would afford a more exact method of identifying particular horizons. Even in the case of rotary drilling, it was possible, by elutriating the sludge which is brought to the surface, to separate off the fine muddy material (whether introduced in the mud, pumped into the well or formed in the well itself), and to leave the coarser sandy material which was being brought up from the base of the borehole.

In the technical application of the science to oil-work, there was a tendency for the Directors of Companies to misconceive the type of information which a geologist is enabled to give. The latter was confronted with a problem, somewhat of the nature of an unsolved equation, often with a large number of unknown quantities. As it was seldom that a complete answer could be given to the riddle, an approximation was the usual result, depending for its accuracy on the methods, skill, and facilities of the investigator, and the difficulties of the investigation.

Mr. E. H. C. Craig considered Mr. Lister James's paper a most admirable one. He had seen a great deal of the author's field-work and his maps, the latter sometimes corrected and altered out of recognition by other people, who, however, had, in the end, to come back to exactly the way the author had mapped them and to his interpretation of the evidence. He therefore thought that Mr. Lister James was well qualified to present such a paper. There were certainly some points in which he did not altogether agree with the author. Taking first feature-recording, this was a good thing to do when nothing else could be done. Something had to be mapped, and if there were no direct geological evidence, it must be a feature, a change in the coloration of the soil, a change in the vegetation, or an outcrop of water; the feature was certainly one of the easiest things to map. Again it was better,

and certainly easier, once there, to keep to the top of the hill, instead of coming down continually, and having to go up again.

In forest ground, however, the mapping of features had frequently led to confusion-mapping. He knew of several cases in Trinidad where geologists of considerable experience had made serious mistakes by mapping beautifully regular features, which they believed were strike features, but which did not follow the strike at all. He would mention another point, namely, with regard to eye-training. Mr. James had spoken of the man who depended upon eye-training as finding himself at sea when he entered a dense forest, where he could not see where he was going. The speaker's experience had been that the man with the best eye-training was the man who was least at sea when he got into a dense forest; he simply had to imagine that there was no forest, and go on mapping. That sounded impossible, but was really not so. The speaker had had something like six months' experience in the training of officers in one of the brigades of the new army, in rapid reconnaissance work—rapid field-mapping and sketching.

He found that his pupils nearly all began with their eyes absolutely untrained. By keeping them continually open, however, judging distances, angles and depths, something like a fortnight's training effected marvellous differences in their work, and some astonishing results were brought out. The work was merely topographical mapping, of course, less complicated than geological mapping, but it had its own complexities and difficulties from the military point of view, and he had been very greatly impressed by the rapidity with which maps and sketch maps, of wonderful accuracy, were made by men who had never attempted anything of the kind before. This experience brought home to him the fact that probably no man was gifted by nature with the faculty of mapping, but nearly everybody could learn it, and learn it with wonderful quickness.

He was sure that had Mr. James been present, he would have very much enjoyed Mr. Illing's highly interesting contribution to the discussion, and have agreed with almost everything in it. The examination of heavy minerals from sandstones had been used several times very successfully, especially in identifying particular oil sands, and he quite agreed with Mr. Illing in thinking that it should be used a great deal more.

On one point perhaps, Mr. Illing was hardly fair to Mr. James. In that part of the paper in which Mr. James discussed the contour mapping of feature, he was considering the mapping in densely forested country, and the author's experience with that sort of

country was chiefly in Trinidad. There, especially in the parts where Mr. James happened to be, the dips were very steep, the strikes fairly constant, and a great many of the complications that Mr. Illing suggested were not in evidence. He felt quite sure that if the author had had time to elaborate that point a little, he would have made the matter quite clear.

To conclude, there was one other point (which perhaps scarcely needed mention) on which he disagreed with Mr. James. This was the hint which the author had given in his paper that the time had passed when the Company promoter would risk his own money upon the bit of land that he had picked out at random. Mr. James might have had more experience, but he (the speaker) had found the Company promoter who ever risked his own money was a *rara avis*.

The President was sure that members would wish him to convey to the author of the very interesting and excellent paper the best thanks of the meeting, and with their permission he would make it his duty to acquaint Mr. James with the appreciative manner in which his paper had been received, and the vigour with which it had been discussed. He would also propose that the thanks of the meeting be conveyed to Mr. Cunningham Craig for so kindly taking upon himself the rather arduous task of reading the paper.

These resolutions of thanks were then put and carried with acclamation.

Nineteenth General Meeting.

The Nineteenth General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, 16th January, 1917, Professor John Cadman, C.M.G., D.Sc., M.Inst.C.E., (President), occupying the Chair.

The Members of Council present were Messrs. H. Barringer, E. H. Cunningham Craig, Arthur W. Eastlake, T. C. Palmer and Sir Boverton Redwood.

The Hon. Secretary (Mr. Arthur W. Eastlake) announced that the following gentlemen had been elected :—

As *Members* :—Montague Bennett Blackler, Charles Barrington Brown (transference from Associate Member), Fred Esling (transference from Associate Member), Samuel Lister James (transference from Associate Member), William Hardy Manfield (transference from Associate Member), Robert Stirling, Thomas Hallowes Vaughan and Professor William Whitehead Watts. As *Associate Members* :—Arthur Philip Catherall, Vincent Charles Illing, Arthur Millar and George John Savage. As an *Associate* :—John Alexander Assheton.

The President said that the author of the paper to be read, Dr. Forbes-Leslie, required no introduction to the members, as they would remember a very instructive paper on the Norfolk Shales read by him at a recent meeting of the Institution. The present communication covered a range which would be of interest not only to members of the Institution but to everybody interested in the technology of petroleum.

The following Paper was then read :—

The Occurrence of Petroleum in England.

By William Forbes-Leslie, M.B., F.G.S., *Member*.

Introduction. The subject which I have the honour to present to you this evening, is one of considerable interest to the country. As far as I know, the possibility of petroleum deposit of economic value being comprehended in strata underlying the surface rocks of England, has not been scientifically dealt with before. Any treatment of the subject on this basis offers, however, considerable difficulty, although less now perhaps than formerly, from more direct evidence having been obtained of the preservation, in certain localities, of free oil in large quantities and the suspicious juxtaposition of those deposits to tectonic underground structures capable of detaining such free oil.

In so presenting the subject that a clear outline of cause and effect can be observed, and a correct perspective result therefrom, a wide field of examination must be covered, and in doing this I crave pardon for trespassing upon your patience, and inflicting upon you a mass of dry details, also for the many faults you may find in their presentation. At the same time, if I succeed in drawing the attention of other and more capable observers to the importance of the subject under view, the object of this paper will have been adequately attained.

History. The districts which, up to the present, have yielded oil in commercial quantities are situated in the north of Britain. But there are, in the south and east, indications of vast quantities of oil-shales capable on exploitation of very largely amplifying, or altogether overshadowing, the production of the former.

In the neighbourhood of the Firth of Forth, the Boghead or torbanite mineral was worked as a source of oil for more than a generation, and since the exhaustion of this, mineral shales belonging to the Calciferous Limestone series have been treated on new and improved methods, with the result that they yield a remunerative interest on the capital invested.

On the coast of Dorsetshire, outcropping in the cliffs at Kimmeridge, there is a series of bituminous shales which have, for many years, been regarded as a possible source for mineral oil of commercial value.

More lately in Norfolk there has been discovered and proved beyond all doubt that a further and probably still more important and practically inexhaustible source of mineral oil exists. In neither of these instances, however, saving in the latter, is there, within the author's knowledge, any indication, in such exposed shale beds, of any true petroliferous strata which might offer the possibilities of developing a great oil industry in this country. Had the necessary conditions, however, been present for the expression of oil from these bituminous shales together with those subserving its retention when expressed, within the area of anticlinal domes, we might have had liquid petroleum in those formations, only awaiting discovery by means of the drill.

From these proved and partly developed sources of industrial oils in Britain, we may now turn to a series of significant oil escapes, including the Norfolk series of shale beds, scattered over the surface rocks of this country without any apparent system in their relationship to each other, or to the various systems of rocks contained in the English Primary or Secondary groups.

These oil escapes may be conveniently divided into three zones, western, middle and eastern.

Oil escapes of the Western Zone. The western zone includes the whole of the country between the third meridian of west longitude, and the Irish Sea, the Bristol Channel and the North Atlantic. It is bounded on the north by a line running north of Whitehaven to the mouth of the River Tees; the western end of the English Channel bounds it on the south.

The most northern occurrence of petroleum in this zone is found at Whitehaven in Cumberland. The next is at Formby on the coast of Lancashire. Here in 1843 Messrs. Binney & Talbot described indications of petroleum at Down Holland. Other indications are found at Ruabon in Denbighshire, and at Merthyr Tydvil in the northern part of the South Wales coalfield. No further occurrences in the western zone are found till the Bristol Channel is passed, when petroleum is again met with at Barnstaple in Devon.

Oil escapes of the Middle Zone. Petroleum occurrences of the middle zone are far more important and numerous than those of the western. They are more important in the physical conditions to which they are subordinate, and in their greater productiveness. They are more numerous, and their geological position is in more direct relationship with later dynamical alterations in the rock structures.

The most northerly occurrences of petroleum are found near Wigan, at West Leigh, Worsley and Swinton. The Yorkshire Coal Measures showed oil at Hemsworth and Dinnington. In the Derbyshire coalfield, an intermittent volume of petroleum mixed with its own volume of water flowing at a rate of 70 to 100 gallons daily was met with at Southgate Colliery, Clowne, near Chesterfield. The rock from which it issued lies at a depth of about 320 yards from the surface.

The most important petroleum seepage in Britain, however, occurred in the Riddings Colliery, Alfreton, Derbyshire. This escape is of historic importance. Dr. James Young, the founder of the Scotch Shale industry, manufactured paraffin wax from this natural flow of petroleum as far back as 70 years ago, but left it to develop the Scotch mineral shale field. For a year or more as much as 7 to 10 barrels per week of this oil was collected and despatched to his northern refinery. Minor discharges are recorded at Barnsley Colliery near Butterley, and at Ilkeston. A discharge of oil from a boring at Kelham, near Newark, was proved to be derived from a source situated beneath the productive Coal

Measures. Here, at 2,452 feet depth, a bed of coarse-grained porous sandstone 15 feet thick, was charged with oil under sufficient pressure to rise freely to the surface against the weight of the superincumbent water. The bearing of this, the most important indication in the whole of the eastern zone, will be discussed later. Flows of oil and kindred substances are also recorded from several points of the Derbyshire Carboniferous Limestone or overlying shales.

On the western side of the Charnian axis, at Longton North in Staffordshire, another petroleum escape occurs. Still farther west in the Shropshire coalfield, petroleum is found at Coalbrookdale and Wellington. In 1836 Dr. Prestwich narrates an occurrence of petroleum at Coalport, and states that this source formerly yielded 1,000 gallons a week. Martin Eele states that occurrences of petroleum are met with at Broseley, Bentley, Pitchford and other places in Shropshire. In 1811 Dr. Richard Bright describes petroleum as exuding from Liassic limestone in the neighbourhood of Bristol, and in 1892 a well near Shepton Mallet in Somersetshire gave several barrels of oil.

Oil escapes of the Eastern Zone. The eastern zone furnishes, perhaps, the most interesting occurrences in Britain. The interest does not so much depend upon the number of escapes, as upon the promising geological conditions subserving the production and possible retention of oil.

The northern line of oil occurrences runs from Filey northwesterly along the Upper Oolite outcrop of Yorkshire. The principal occurrences are found at Filey, Pickering and Kirkby Moorside.

Oil has been found at Brigg in North Lincolnshire, and along the outcrop of the first division of the Upper Oolites at Market Rasen, Haugmont, and Donington-on-Bain.

A line of oil occurrences begins at King's Lynn on the Wash and runs southwards along the strike of the Upper Oolite outcrop as far as Cottenham in Cambridgeshire. The principal occurrences are at King's Lynn, Downham, Littleport and Ely.

The information obtained by the above-mentioned borehole at Kelham is a factor of great value when taken into consideration and applied to an analytical review of the oil seepages in England. It is a positive proof that a true oil-bearing stratum underlies the surface rocks at any rate in one part of the British Isles, and when it is considered in relation with the surface position of the oil escapes on the eastern flank of the Pennine Chain, it suggests a possible connection between those underground sources of oil

and those surface escapes which are scattered, seemingly at random, along the Eastern flank of the Pennines.

The result is that a suspicion rises of well-defined underground structures traversing parts of England and carrying oil, just as such underground structures have been proved on the Continent and in America to be the source of oil in those productive areas.

With these instances of oil-bearing strata, we may assume that our present knowledge of the subject terminates. But the very indications above cited, and which, apart from the Kelham discovery, appeared to most observers to possess nothing more than a mere academic interest, taken in conjunction with this more significant instance, stimulates one more critically to examine the subject at issue, in order to determine really whether these old and apparently deceptive surface-indications of the presence of oil-bearing strata in the British Isles may not, after all, compare favourably with similar occurrences in foreign fields, which were the causes of inducing capitalists to investigate the possibilities of oil being found in commercial quantities at depth.

An endeavour will be made in this paper to demonstrate that the examples above cited do not close the field of examination but, on the contrary, do much to disperse the darkness which till now has enveloped the subject, and which, if examined in the true light that science demands should be used for its elucidation, may result in the detection of petroliferous deposits in the British Isles of a character and productiveness commensurate with the visible and significant surface escapes which till now have been relegated to a place of subordinate merit.

Situation of Petroliferous deposits. Careful study of the possible occurrences of liquid oil in Great Britain leads one naturally towards the eastern portion of that island, where past tectonic conditions and the structure of the areas of depression are such as to favour the production and retention of petroleum.

The oil escapes of the Eastern and immediately adjacent section of the Middle zone group themselves into three distinct but related series.

The first series is found in Nottinghamshire and Derbyshire, especially in those districts lying between the river Humber and a line drawn from Castleton in Derbyshire to Retford in Nottinghamshire. The second series are located in Derbyshire and Nottinghamshire, south of the Castleton-Retford line, and are found especially along the area comprised between Winster on the west and Kelham on the east. The third group or series is confined to the more eastern portions of England, running from

Cambridgeshire through the northern and western portion of Norfolk and extending north-westwards through Lincolnshire to the Humber. These districts when approached from the tectonic side of the subject, will be found to correspond to four well-defined folds in the rocks, one of which is visible at the surface, one which has been proved by deep boreholes, and two which have been detected more perhaps by stratigraphical examination than by the more positive procedure of drilling operations.

Topography. The topography of the country underlaid by possible oil-bearing strata is not particularly interesting, except from the occurrence of large areas of flat country, or of low-lying land, diversified here and there by more elevated masses of rolling ground. Whoever has travelled through the counties of Nottinghamshire, Lincolnshire, Cambridgeshire and North Norfolk will understand the meaning of this general definition of the landscape.

Westward of the Fen depression, and the rolling plains of the Nottinghamshire syncline, there meets one the rising bank of the Pennine Chain, culminating in the Peak of Derbyshire. As, however, at all events in England, the productive anticlines will probably be found to be more truly the concealed ones, the search for visible indications of such subordinate anticlinal forms will be found of special account in a study of the English petroliferous rocks.

Orographic Movements. At the outset, it may be taken as a fundamental fact that the materials for the greater part of the dry land have been laid down upon the floor of the sea, and mostly within the limits of confined inland seas. That they did not still remain in this subordinate position, but have risen above the sea level as terrestrial plains, or are reared up into lofty mountains.

Upheaval in fact has been locally confined to areas where portions of the crust have been ridged up by the enormous tangential thrusts of adjacent subsiding regions. These tracts or regions of strains, bounded by consecutive and well-defined lines traversing the super-crust and sedimentary beds of the planet, have usually yielded to pressure again and again during geological time. They constitute the terrestrial regions of the earth's surface. The general result of such terrestrial movements has been to throw the crust of the earth into wave-like undulations.

Certain well-defined facts stand out. The principal may be cited as a definite law of configuration of crustal surfaces that, from the earliest geological time, of which there can be no record, and also throughout all the geological periods succeeding, the planet has been undergoing deformation from hypogene and

epigene action, yet the lines of strain have been constant throughout, so that the oscillations resulting therefrom have operated more or less in the same direction and degree, and the mountain ranges of early Archæan times have formed the protaxes for all succeeding orogenic movement.

These movements subserve those conditions which are necessary for the source and retention of the materials from which emanate petroleum and its compounds. They also supply those chemical requirements which are necessary in the various destructive changes which carbonaceous matter and dead organisms must undergo in their progress towards the production of petroleum.

Petroleum is found in all geological systems, from Silurian to Eocene and Miocene, and has its origin either in vegetable matter or the organic remains of animals or fish, by destructive distillation at low temperatures, or by powerful oxidising agents as when alkaline metals or iron at white heat are caused to react with steam and carbonic acid, the hydrogen of the water and the carbon of the carbonic acid, deprived of their oxygen, uniting in a nascent state to form oily fluids resembling petroleum.

Geological Range of Petroleum. Petroleum was first struck within the limits of the Silurian and Lower Devonian divisions in America, where the oil escapes in the Eastern States were least known and do not appear to have been more important or significant in their relation to underground structures than the seepages we have already described as occurring in England.

The Tertiary divisions in this country do not appear to contain evidences of liquid oil. It is only in the lower division of the Upper Oolites that bituminous bearing shales are found from which oil can be obtained by artificial means, but, unless the Liassic oil mentioned above as occurring near Bristol is a true indigenous oil, no real oil zone of a petroliferous character is discernible in the English formations until the Carboniferous horizons are encountered. Any escapes of oil on the surface of younger formation only demonstrate that their origin is deeper seated than the rocks from which they issue. Thus, the escapes at Filey, Kirkby Moorside, Brigg, Market Rasen, Haugmont (Horncastle), King's Lynn, Downham, Littleport and Ely, are all on the surface of Jurassic rocks, but when we come to an analysis of the tectonic structures underlying or in the immediate neighbourhood of these escapes, it does not seem logically credible that the origin of the oil is Jurassic. The whole strength of the argument presupposes, when examined, a Carboniferous or earlier origin.

Likewise, the escapes at Stockton and Middlesbrough are on

the surface of Trias rocks, but it is a foregone conclusion from our knowledge of the Trias horizons in Britain, that they are generally barren in the materials from which oil is produced. A Carboniferous or pre-Carboniferous origin for such escapes is the only logical conclusion.

The great and in some cases historical occurrences of oil upon the surface of Carboniferous rocks at Alfreton, Clowne, Wigan, Westleigh, Worsley, Ilkeston, Longton, Coalbrookdale, Wellington, Coalport, Priorslee, Broxley, Bentley and Pitchford are all indications of a Carboniferous source for the oil.

The relation of Britain to the European Continent is a question of paramount importance in the search for mineral oils in submerged strata. A true perspective of past events in terrestrial history is necessary in any examination of the subject. In an examination of the hidden topography of Palæozoic or earlier England, a just apprehension of past events can only be accumulated by laborious effort, seeking to correlate a mass of evidence partly or wholly hypothetical with a few main outstanding and self-supporting facts. These are the corner-stones of a synthetical system, only made possible of construction after analysis of all facts has established a balance between conflicting evidence, and introduced the harmony of one overruling voice for that of the many.

In pursuance of this principle of scientific investigation, it is not possible to present the subject in less proportions than the whole, for not knowing the beginning, we cannot justly understand the present, nor conceive that which is to come. So, we cannot understand Britain until we have knowledge of the wider facies of European formations, and the law of their genesis out of the rib of a greater though now invisible continent.

Great Britain stands on a broad Continental border, over which the depth of the sea does not exceed 600 feet. It belongs to the European Continent, but during the period of the Coal Measures, and for untold ages anterior to these, this platform apparently belonged to a great north-western Continent. Since the Palæozoic era, the sedimentation of Britain has been successively on the east and south, while the diminution of its platform has been successively from the west, so that to-day the old lands of the prehistoric continent are reduced to the crystallines of Wales, Cornwall, Cumberland and Scotland, while the new terrains of the middle and east constitute the greater mass of the island.

The North Sea, which separates Britain from the European mainland, is nowhere over 95 fathoms deep, and therefore must

be taken to form part of the Continent itself. The feature-lines common to Europe, must naturally extend to the Island of Britain and link up this mass of land to the greater mass of the Continent.

The intrusion of the North Sea and the Channel between the visible terminals of these feature-lines, in no way affects their existence or the power they inherently possess of ultimately affecting the future modifications of the Continent as a whole. Each section of the European mass has a factor common to all. England, no less than France, is the child of tectonic causes affecting Europe: they are bound together geologically by indissoluble bonds. These bonds are the lines of force, bisecting and traversing the Continent, which likewise have established a concentration of substance more inherently crystalline than the contents of the intervening depressional areas.

These metamorphic series comprehend tracts or ribs, traversing the Continent in various directions, but invariably falling if sufficiently prolonged into two cardinal directions, northwest and northeast. These are the European radicles of the two great systems of trends which divide our planet, and are common alike over land and sea. Their hidden parts correspond to the floors of the numerous basins or irregular depressions which everywhere comprehend the converse tectonic form. Whatever may be the visible outline of the depressions, these are in every case composed of the sectional tracts or paths of force which form the natural confining rims. Everywhere, likewise, it is possible to perceive, even in the most irregular area, a remarkable tendency towards a circular shape, and it is possible in most cases, upon projecting the principal features, to arrive at an approximate circle, which is the primary objective of all terrestrial substance. Nevertheless, in this paper, in order to avoid confusion of terms, the more abstract term "depression" will be employed instead of basin, which, in many instances, more accurately describes the area.

The East of England Depression. More perhaps than any of the other depressions of the British platform, which, unfortunately, cannot from want of space be here examined, although all are integrally related, the east of England depression has its crystalline boundaries concealed from view beneath the cover of younger rocks, and it is for this reason that so little is yet known of its floor and the folds which comprehend its sectional arrangements, and give shape and position to those later sediments which compose its contents.

The results of boreholes, however, have done much to increase

our knowledge, and moreover enable a general idea of the system upon which the floor is outlined to be grasped.

This specially applies to the northwestern section of the depression, where the location of productive Coal Measures has caused numerous and closely related boreholes to be put down, but the southern and eastern sections are still, comparatively speaking, geologically unknown, as far as their deeper seated rock formations are concerned. With one or two exceptions, which are confined to the southern section, the boreholes put down have been too shallow to penetrate any but the most superficial members of the series covering the area.

The western boundaries are formed by a tract of crystalline rocks apparently extending from Auxerre through the Boulonnais, by Brabourne to Streatham, whence it runs by Richmond, through Buckinghamshire, etc., to the visible cores of the Charnian axis at Nuneaton and Charnwood Forest, and thence by the Pennine anticline to the Silurian ground in Westmorland and Cumberland, terminating in the Scottish massif.

Although the Auxerre-Boulonnais-Brabourne line is so intimately connected with its western line of circumscription, that the eastern depression of England may be said to be regionally connected with the Central European depression, yet there are subordinate transverse courses within it, which can, although deeply concealed, be brought into evidence in order to define the independent sectional arrangement. On such positive evidence as borehole results, the eastern depression may be shown to be limited on the south by a general east and west line of folded crystalline, or Lower Palæozoic rocks, having the London platform on the west, and other masses independent or in alignment therewith on the east. The general axis of these rocks lies along the centre of the old submerged Thames valley, east of Essex and Suffolk. Other protaxes of pre-Palæozoic rocks form subordinate ridges farther westward, but parallel to the first. Since the pre-Gault period, the axis of movement lies east and southeast of the English coast.

The North Sea area. Just as the eastern depression of England is intimately connected with its central European counterpart through the east of England Channel depression, so is it in intimate relationship through the North Sea sub-depression with the eastern section of the same central European area. Following the axis of the English Channel east of the Straits of Dover, it is found to curve gradually northeastwards and then due north to the southern extremity of the western border of the Well Bank, along which

it runs to its northwestern extremity, where a triangular trough is presented with its base towards the English coast.

The northern margin of the Well Bank, if projected to the southwest, will make the eastern border of the Wash along the course of the Ouse and Nen rivers, while the southwestern extremity of the Dogger Bank is turned south-southwest along a line that if continued will form the western margin of the Wash. The configuration of the Wash is seen to enter into conformity with, and evidently forms part of, the general submerged outline of this portion of the North Sea.

The angular alignment of the Dogger and Well Banks to each other, and the remarkable conformity of the projected lines of configuration with those of the chief marine indentations on the east coast of England, is a matter of considerable significance. It has a very even and general conformity. For a study of the submerged features of the North Sea evolves a sectional system of arrangement in complete harmony with those of the terrestrial platform, and it is not possible that the arrangement and direction of the marine currents, influenced by coastal configuration in this part of England, can have resulted in building up a series of submerged features in such complete harmony with those of the land, unless the features on the floor of the North Sea and English Channel are the remains of submerged land, which have attracted sediments from time to time, accumulated and superimposed upon them but without masking the general configuration of their masses.

Unless proved positively to the contrary, this suspicious physical similarity in the terrestrial and submerged features of the east coast of England and western North Sea floor, presumes that the Dogger, Long and Well Banks are the geological counterparts of that sectional arrangement which is visible on the land, and permits the drawing of the eastern limits of the east of England depression along the western borders of these banks. The peat covering parts of the Dogger Bank attests the recency of at least the latest submergence.

Nature of the forces affecting the depression of eastern England. Two great forces exist in Nature, and are exerted upon the globe: that arising from its movement and rotation in space, and that arising from overloading of the crust within limited areas. The first force is oblique to the axis of the globe, and has general alignments northwest and northeast to its axis. The second force depends upon the contact of an ocean, or body of water of such extent and depth as to be capable of developing a sufficiently powerful thrusting force, and upon an abundant source of sediment

to form the load. The latter force must necessarily, from its character, be erratic in degree, although it is generally subordinate to the first, and will ultimately conform its system of direction and arrangement thereto.

England exhibits its main feature-lines along the northeast system of trends. Its more subordinate and, perhaps, later feature-lines are along the northwest system, and it is the appositional contact of these two systems which produces the sectional arrangement of the eastern depression of England, as it does generally within all its other sub-depressions.

The two systems have received the names, not wholly acceptable, as being too local in their connotation, of Caledonian, N.E.—S.W., and Charnian, N.W.—S.E., whilst the east and west system of Southern England is known as the Armorican, from the ancient name of Britanny.

The force which has produced the folded arrangement of the terrains within the eastern depression of England, has been a thrust developed in the east and southeast, while there is also evidence of a thrust developed from the northeast.

The nature of the force affecting the Anglo-Irish depression in early Palæozoic time, was probably a thrust directed from the north-northwest, and the resulting uplift was partly geanticlinal and partly geosynclinal, the complete process being more or less compensatory and epeirogenic. The geosynclinal axes were also on southeast-northwest lines.

On the close of the Silurian period, a general epeirogenic movement was responsible for a shallowing of the entire area. Upon the surface of the elevated tracts, large Old Red Sandstone basins were formed, which appear to have been the remains of geosynclines of accumulation.

The transverse course from Bardon Hill to Church-Stretton dividing England into a north and south depression, seems to have divided the Devonian period dynamically into two phases. The thrusting force of Devonian time was apparently eastern and southern. The advent of the Carboniferous period depressed the main portion of the Silurian and Devonian area, for throughout the Lower Carboniferous division a deep and wide sea lay across the centre of Ireland and England into Europe. The Continental mass lay northwest and south of the limestone sea, forming a Palæozoic Mediterranean.

The uplifting force which was responsible for the shallowing of the limestone sea, and the advent of shallow-water conditions expressed in the Millstone Grit and Coal Measures was generally

an epeirogenic one, affecting the eastern part of the old Palæozoic Continent.

The rock stresses which had been accumulating throughout the Carboniferous period, and which had not been entirely accommodated by the more or less rhythmical oscillations of level affecting the Continental border, found relief at the close of the period in a general folding of the strata along a northwest-southeast line of strike.

The thrusting force being evidently directed from a northeast and then east direction, the result was to produce a repetition of folding along the early crystalline feature-lines in a general northwesterly course.

The farther east we go from the crystalline masses of England and Wales, the more radical in direction does this folding become, and the more remarkable is the parallelism displayed by the complementary folds.

At the close of the Jurassic succession, a tendency towards a more general southern thrusting force was observed in the Chalk period from the possibly renewed stability of the Eastern Plateaux along the Peterborough-Culford-Debenham-Orfordness line in correspondence with the London platform, giving the thrusting force a southeasterly direction, which is shown by the deepening of the Chalk southeast of the line, and also by a certain thinning out over it of the Chalk and even of the Gault.

The Oligocene movements did much to intensify the presence of the Peterborough-Culford-Debenham-Orfordness line, and to demonstrate its stability against a general eastern subsidence of that portion of the London platform and west of it, which had been included in the Eocene synclinoria. The greatest changes in geological structure, therefore, were experienced in the Hampshire basin, as the effect of Oligocene movements. Two forces are expressed in an examination of the Gault taken as a standard of level: a violent southern thrusting force and an eastern foreshortening force. These results were due to the general subsidence affecting the basin of the Seine, Holland and Prussia and the bed of the North Sea throughout the Tertiary period.

Description of visible external sectional arrangements of the eastern depression formed by anticlinal ridge folds. Two standards of level only are possible within the radius of the eastern depression. One is situated in the Upper Palæozoic, and is formed by the Coal Measure Series. The second is obtained by a study of the Gault, but the latter is limited in its area to the south of England. From these two standards of level, it is possible to demonstrate

changes that have taken place since the deposition of the geological series, immediately previous and subsequent to the Coal Measures and Gault.

In order to study the genesis and ultimate growth of the eastern depression, it becomes necessary to allocate to the two systems of trends all those major folds traversing the terrains of Britain, which are visible in whole or in part. The lesser folds, which are more or less complementary to the principal ones, are not always visible, although in many instances indirect evidence goes far to prove their existence, and they are directly demonstrable by means of the drill or other absolute means of evidence.

As the growth of Britain has been throughout the later geological ages successively eastwards and southwards, so it is necessary, in any survey of this nature, to trace the feature-lines from west to east. For, in the former position, the evidence of a genesis in movement inferring conformity of purpose towards objectivity of form and outline attests itself and is capable of ocular demonstration.

Referring to the paragraph dealing with the force affecting the English areas, it is found that England exhibits its main feature-lines along the Caledonian system of trends, and its more subordinate and perhaps later feature-lines on the Charnian system, and it is the appositional contact of these two systems which produces the angular arrangement of the outcrops of later geological deposits, a form which is singularly apparent in the Welsh crystallines, and becomes accentuated more and more as the angle is projected eastward. These two trends likewise produce a system in the sectional arrangement of the eastern depression, as they do in all the other English basins.

The force affecting the ancient crystalline series of Britain was, in its nature, largely planetary in origin, while assuming that the polarity of the earth was the same as now, which does not appear to have been the case, the direction of the force was northwest from the North Atlantic and Polar Oceans.

An examination of the exposed basement rocks leaves no doubt of this fact, nor is it less open to demonstration that the principal feature-lines of Britain are on the Caledonian system.

In Anglesey, Carnarvon, Merionethshire, the pre-Cambrian, Cambrian and Silurian formations are all deeply folded upon this system. Towards the south in Pembrokeshire, the Armorican system prevails, the centre of the greatest impulse being situated in Cardiganshire, where a yielding of the platform has taken place, with an accentuation of the arcuate form. It is here where

the angular outline of the later English formations has its genesis. It is more or less traceable beneath the Midland terrains to the Charnwood Hills and their southward outliers, and probably only terminates with its extension beyond the Wash area.

The formations south of this arm are folded in an east and west direction. On the north they lie more or less northeast or west.

The next fold eastwards of the Carnarvon area is met with at Church Stretton in Shropshire. Here the axial direction is northeast-southwest, the younger crystalline series dipping away on the northwest and southeast of it. The next fold is at Walsall, where the Ludlow group outcrops. Apparently the direction of strike is more or less northeast-southwest, with some northing in it. Though the line is difficult to determine, it is obviously not west of north.

At some distance east of this outcrop of Silurian, there is the Leicestershire area, where the Nuneaton anticline, the Bosworth anticline and the Charnwood Hills are of transverse trend, being on the Charnian system. These outcropping ridges of old rock cease along northeast-southwest synclinals or valleys of great depth, in which are situated Derby and Grantham on one side, Rugby and Kettering on the other.

It is within the area extending from Nuneaton to Charnwood that the Charnian axis meets and considerably modifies the ancient system of folding common to the Primary series. In the focus of such modifications, the tangential strain induced by the meeting has resulted in fracturing of the older rocks with outpourings of lava. Once the meeting of the two systems is past, the parallelism of the Caledonian system of foldings is more apparently demonstrable, and farther south and east subordinates, without altogether obliterating, the Charnian.

It would be well to study the northern aspect of the eastern depression, where a fold of the earlier system (the Caledonian), or something akin to it, forms the northern delimiting line. And by tracing southwards the complementary folds induced by its rise and influence, a complete understanding can be obtained of this series of foldings in the growth of form and in the contents of the eastern depression.

The Wharfe axis. The existence of this axis is demonstrated by the following evidence. In the western section, the Millstone Grit between the coalfield and river Wharfe dips in a general southerly direction. In general structure, the strata in this area partakes of an anticline, the axis of which lies along the course

of the river Wharfe, and although after the oncoming of the Triassic and younger cover no evidence remains of its farther extension, the fact remains that if it be projected along what would be its natural line of strike, it would meet the Chalk Wolds on the crown of, perhaps, one of the most remarkable ridge-folds in the whole depression. It is impossible without making serious analytical errors, to consider such evidence as merely incidental, and the term of Wharfe axis will be adopted in future in this paper for the anticlinal structure running along the Wharfe valley to Market Weighton, Beverley and Aldburgh.

The Wharfe axis forms the northern boundary of the eastern depression, and suffices also to separate the latter from the north-east depression. It is best to define the Wharfe axis as a broad fold running in an east-southeast direction. Its southern slope falls gently down to the river Aire, along which it may be said the extreme southern slope of the axis lies.

From borehole results it would seem that the Wharfe axis is steeper along its southern than its northern slope. The complementary folds of which there is any suspicion are more affected in direction as they proceed southwards. The liberation of the lateral thrust through fracture of the Wharfe axis into the area of the eastern depression may have a great deal to do with these modifications affecting the subordinate folds of the depression. But the attempt of this thrust to swing the Wharfe axis into parallelism with the Pennine and Charnian axes, must have had a prior influence in compressing the area between them.

All evidence goes to show that the Wharfe axis has been in existence since inter-Carboniferous or pre-Permian time.

Complementary folds south of the Wharfe axis. In making out the characteristics of the Wharfe axis, Professor Kendal has shown that, subsequent to the elevation of the Kimmeridge clay upon an east and west line to the south of the Chalk escarpment now overlooking the valley of Pickering, observed first by Mr. Lamplough, and confirmed by Mr. Strangways, greater movements took place along the whole line of the chalk escarpment from Caister in Lincolnshire to Acland in Yorkshire. The evidence accumulated from an examination of the results is that these were movements of a fundamental nature, and the folds established in the overlying younger rocks are probably superimposed upon more ancient folds comparable in time to the Wharfe axis itself. This opinion is, however, rejected by some eminent geologists, and the matter is, therefore, more or less a subject open to discussion, until proved by more absolute evidence.

A study of the surface features along the line of disturbance west to east, is productive of rather significant evidence. Along the Chalk escarpment, especially in the neighbourhood of Caister, the Jurassic rocks, according to Professor Kendal, are thrown into a series of convolutions expressed in such surface forms, and running in general from west to east, or west-southwest to east-northeast.

Farther west from Caister, the Lias, Trias and Permian exhibit a slight synclinal depression from Scotton to Conisborough, continuing in a course deflected to west-southwest in the Coal Measures to Sheffield, and there more strongly marked. The Trias is of greater thickness here, implying pre-Triassic subsidence between the Wharfe axis and that to be presently described south of Nottingham. To the southward of the Sheffield syncline, a complementary anticline runs from the crest of the Pennine Chain near Castleton, east-northeast by Hathersage to Norton, and thence east-southeast towards Tuxford and the Lincoln gorge, the latter portion being approximately parallel to the Wharfe axis.

Movements of late Jurassic time affecting the Caister end of the synclinal seem to have been of an elevatory nature, causing folding of the younger series. It is possible that the syncline lies upon an old line of disturbance established at a period anterior to the Carboniferous, and that a repetition of such oscillatory movements as first effected it was responsible for the folding seen at Caister and along the Wold escarpment.

In Permian times a bank of high land ran due west and east immediately south of Nottingham, for no Permian rocks appear in the borings at Owthorpe, Ruddington or Hathern, whilst farther west the Trias rests directly on various members of the Carboniferous or older rocks.

The sinking of this area beneath the Trias sea continued intermittently throughout the Liassic and Jurassic periods, in which estuarine conditions recurred from time to time, and shallow alternated frequently with deep waters. The movements were doubtless influenced in direction and amount by the structure of the older rocks below them, but there is not space here to discuss the details of that influence.

The course of the Welland river follows the northeast trend of the Caledonian system with singular straightness. It rises near Market Harborough, between the granite ground of Countesthorpe and the quartz-felsite ground of Orton, flows northeastwards to Market Deeping, and then turns north-northeast to its mouth in

the Wash. At Pinchbeck, near Spalding, the Lower Oolites rise to within 70 feet of the Fenland level.

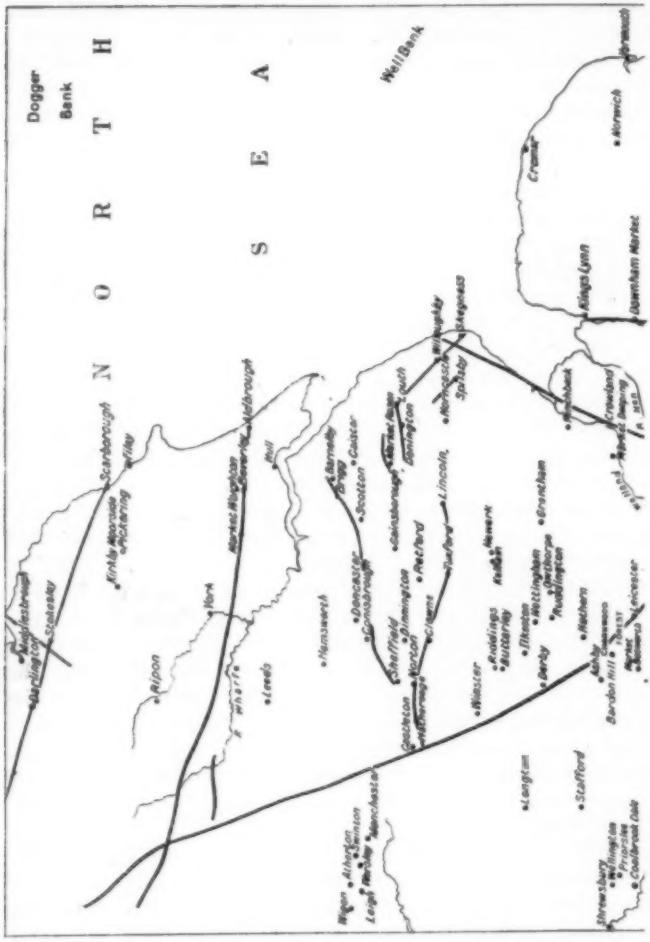
Immediately eastwards, and approximately parallel with the Welland river, there is the Nen river, which taking its rise west of Northampton, runs past the boring made near that town at Gayton, where Old Red Sandstone was found under Carboniferous Limestone, and then through Peterborough, to debouch in the Wash between the mouths of the Welland and the Ouse.

South of the Nen, and largely parallel with its course, there is the Bicester-Yaxley anticline, so named by Professor Kendal, but for which Islip-Yaxley would be a more appropriate term. For a large part of its course, the Nen conforms exactly with the direction of this anticline, which is approximately parallel with the line of the adjacent borings of Calvert and Bletchley, where old crystalline rocks were reached. It is significant that a line connecting these two borcholes falls in a general way, if projected, along the course of the river Ouse, passing through Bedford, where the strike of the Lower Oolites bends at a marked angle over the main Charnian anticline. Its farther course along the edge of the Greensands and Ouse crosses the fold in the Kimmeridge series called the Ouse Valley outcrop, where that flexure exhibits an inlier of Corallian rock at Upware.

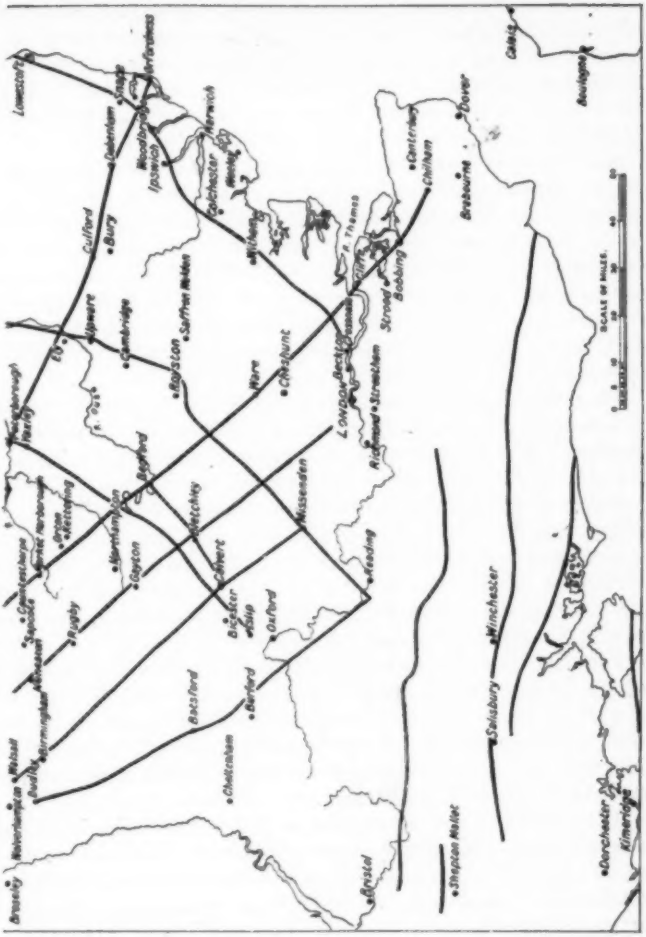
The determination of the fold running north and south between Lynn and Downham Market and extending thence to Upware near Cambridge, has been demonstrated by recent fieldwork to exist as an integral underground structure of those districts. The flank of its northern extremity dips rather steeply towards the Nen, while its eastern side possesses a lower degree of inclination. It has an important bearing on the overlying series, and does not appear to be a superficial structure affecting merely the Jurassic rocks. It will probably be found to be an anticline of considerable economic importance.

A line of disturbance believed to be of a superficial nature has been observed by Mr. Jukes-Browne in the Cretaceous rocks running between Royston and the valley of the Cam, and it may be that the farther westward extension of the Ouse valley fold is via this anticline to the Silurian ground of Great Missenden. If this were the case, the river Nen would be the continuation of the Calvert-Bletchley-Bedford line, and a synclinal might be expected to exist between the Nen and the Ouse.

In the south of England and west of the Charnian axis, the London platform and the Kentish axial line, the later movement was effected upon east and west lines, and thus there came into



being the Wealden anticline and many lesser folds to the west and north of it. These lines of flexure, in passing over the crown of the Charnian axis were, however, deflected into a northeasterly trend across Essex to the Culford-Weeley crystalline massif, beyond which, encountering the oblique Peterborough-Orford Ness axis, they were swung northwards in a complementary curve till lost in the submerged terrains of the North Sea beyond Yarmouth.


Lowestoft
Harwich
Colchester
Culford
Bury
Ipswich
Cambridge
Saffron Walden
Royston
Hitchin
Hertford
Watford
Harrow
Hendon
Kensington
Clapham
Wimbledon
Epsom
Reigate
Guildford
Aldershot
Basingstoke
Reading
Oxford
Banbury
Rugby
Leamington
Warwick
Birmingham
Redditch
Bromsgrove
Worcester
Malvern
Hereford
Ross
Monmouth
Chepstow
Gloucester
Cheltenham
Stroud
Swindon
Bristol
Bath
Weston-super-Mare
Taunton
Exeter
Torquay
Plymouth
Salisbury
Winchester
Southampton
Portsmouth
Chichester
Brighton
Eastbourne
Hastings
Dover
Canterbury
Chatham
Gravesend
Tilbury
Southend
Maldon
Chelmsford
Braintree
Bishop's Stortford
Harlow
Epping
Enfield
Barnet
Watford
Uxbridge
Staines
Windsor
Slough
Bracknell
Basingstoke
Andover
Salisbury
Dorchester
Weymouth
Bridport
Lyme Regis
Honiton
Exeter
Newton Abbot
Torquay
Plymouth
Launceston
Bude
Wadebridge
Truro
Penzance
Falmouth
Redruth
Camborne
St Ives
Helston
Newquay
Padstow
Bodmin
Liskeard
Looe
Saltash
Tavistock
Okehampton
Crediton
Tiverton
Wellington
Taunton
Bridgwater
Minehead
Barnstaple
Ilfracombe
Lynton
Dulverton
Wiveliscombe
Chard
Lyme Regis
Bridport
Dorchester
Weymouth
Portland
Swanage
Poole
Bournemouth
Christchurch
Lymington
Ringwood
Fordingbridge
Romsey
Southampton
Eastleigh
Fareham
Gosport
Portsmouth
Havant
Petersfield
Midhurst
Haslemere
Godalming
Guildford
Dorking
Leatherhead
Epsom
Kingston
Richmond
Twickenham
Hounslow
Brentford
Ealing
Acton
Willesden
Hampstead
Highgate
Finchley
Barnet
Edgware
Harrow
Wembley
Hanwell
Southall
Hayes
Uxbridge
Rickmansworth
Watford
St Albans
Hatfield
Hertford
Ware
Hoddesdon
Cheshunt
Waltham Cross
Enfield
Edmonton
Tottenham
Walthamstow
Leyton
Wanstead
Ilford
Barking
Dagenham
Romford
Upminster
Grays
Tilbury
Gravesend
Rochester
Chatham
Sittingbourne
Faversham
Whitstable
Canterbury
Ashford
Tenterden
Hastings
Eastbourne
Brighton
Worthing
Littlehampton
Bognor
Chichester
Havant
Portsmouth
Fareham
Southampton
Romsey
Andover
Basingstoke
Reading
Wokingham
Bracknell
Windsor
Slough
Maidenhead
Henley
Wallingford
Abingdon
Oxford
Witney
Chipping Norton
Moreton-in-Marsh
Stow-on-the-Wold
Bourton-on-the-Water
Cirencester
Tetbury
Malmesbury
Chippenham
Calne
Devizes
Marlborough
Hungerford
Newbury
Thame
Aylesbury
Tring
Berkhamsted
Hemel Hempstead
Chesham
Amersham
Beaconsfield
Gerrards Cross
Uxbridge
Rickmansworth
Watford
St Albans
Hatfield
Welwyn
Stevenage
Hitchin
Baldock
Royston
Saffron Walden
Great Dunmow
Braintree
Witham
Maldon
Southend
Rayleigh
Billericay
Brentwood
Romford
Hornchurch

Briefly described, the Charnian axis is composed of a complex of sheared and shattered rocks occupying the tract of the Charnwood Forest from which it takes its name. Long before Carboniferous time, these very ancient crystalline rocks were bent, in this locality, into an anticlinal form running roughly northwest and southeast.

The extension of the axis can be traced as far south as Bulbourne by two classes of evidence. It can be taken to occupy a northwest-southeast line from Bulbourne near Tring in the south, where it unites with the northwestern slopes of the London platform, to Nuneaton and Charnwood. Beyond Derby, it comes into view again in the Lower Carboniferous rocks of the Pennine axis. Southward from the London platform it crosses Kent to the Boulonnais and Auxerre, bordering the Central European depression

Its influence as an immovable buttress in relation to forces directed from the northeast-southeast and east has had an important bearing in the establishment of present tectonic features within the eastern depression of England generally.

Signs of persistent folding on the Charnian axis. With few exceptions, almost every subdivision of the Jurassic and Cretaceous rocks show signs that the Charnian axis partook in every movement of accommodation. Formations that northeast or southwest of the axis are well developed, dwindle down, and even wholly disappear when the axis is reached.

For instance, the Trias beds, which have a thickness at Batsford of 553 feet, dwindle down at Gayton to 82 feet, to 67½ feet at Kettering Road, Northampton, and to 27 feet at Orton. At Burford the aggregate of Lower Oolites, Lias, Trias and Coal Measures passed through, has a thickness of 1,410 feet, but has entirely disappeared at Bletchley.

The Inferior Oolites undergo a remarkable attenuation in Northamptonshire. The limestone beds diminish in thickness, and as the axis is reached, exhibit a lithological change, becoming more and more sandy. The beds also successively disappear by erosion effected before the Great Oolite period.

Southwestern boundary of the eastern depression. The London platform is the remains of old mountain ranges which throughout the Lower Jurassic and succeeding periods, up to the Gault, formed an immovable barrier against the thrusting force, coming from the east and southeast, of the Central European depression.

The Old Red Sandstone sea, however, which occupied such wide areas in the south and west of England, must have covered the

Silurian floor, for we find by deep borings at Southall, Willesden, Meux's Brewery, Streatham, Chiswick and Richmond, Old Red Sandstone rocks underlying the Lower Oolites and Gault. On the east of London the Old Red Sandstone is met with at Beckton and Cheshunt.

The Silurian area of Calvert, Missenden and Batsford, probably connected with that of Ware, Cliffe and other points in Kent, would appear to limit the Devonian on the north, though it recurs at Gayton, through some undiscovered channel. On the east and southeast, Cheshunt, Beckton and Brabourne are within the Devonian limits; Cliffe, Bobbing and Chilham are on Silurian, but the Devonian may recur eastward of them, in a belt fringing the Kentish Coast Carboniferous basin.

The Palæozoic floor rises under London to the base of the Gault from Ware to Streatham, but in Western Middlesex and Kent the Lower Greensand, Jurassic and Triassic beds come in between, in attenuated form, abutting against the flanks of the "platform," which a post-Gault flexure of Charnian trend has recently been shown to traverse.

Probably the northern boundary of the London Devonian is sharply indented by several subordinate flexures of the Charnian system, whilst the eastern, being along the strike, will be more direct in its course.

The most westerly Charnian axis extends from Dudley, through Batsford to Reading, where its course seems to be established by the magnetic survey effected by Messrs. Thorpe and Rücker. The Walsall-Calvert-Missenden line is approximately parallel to this, and next comes the Leicestershire trio, of which the Nuneaton-Gayton-Bletchley line points to West London, the Ashby-Sapcote-Northampton-Bletchley line to Beckton, Crossness and Brabourne and the main Charnwood-Orton line through Bedford, Ware, Cliffe and Chilham to Folkestone and the Boulonnais.

The term Eastern Plateau may with some justification be applied to define the eroded fragments of what may once have been a mountainous country of Silurian or earlier rocks, comprehending the floor of the Eastern Counties, and separated from the London "platform" by the depression existing between Ware and Culford.

Weeley and Culford are the nearest points at present known to the central group of Charnian folds, but as apparently the crystalline mass extends to Lowestoft, the axis may pass anywhere in the interval. The protraction of the Louth anticlinal would pass across Norfolk to Orford Ness. Here again a transverse

Hemsworth
Barnelby
Brigg
Doncaster
Caister
Conisbrough
Scotton
Gainsborough
Market Rasen
Louth
Dinnington
Donington
Retford
Clowne
Willoughby
Lincoln
Horncastle
Tuxford
Spilsby
Riddings
Newark
Kelham
Butterley
Ilkeston
Nottingham
Grantham
Owthorpe
Ruddington
Pinchbeck
Hathern
CHARNWOOD
FOREST
Crowland
Market Deeping
R. Welland
R. Nen
Market Bosworth
Leicester
Peterborough
Countesthorpe
Yaxley
Sapcote
Market Harborough
Orton
Kettering
Rugby
R. Ous
Northampton
Cambridge
Gayton
Bedford
Royston
Bletchley

SCALE OF MILES.
0 5 10 20 30 40 50
NORTH
SEA
Well Bank
Skegness
Cromer
Kings Lynn
Norwich
Yarmouth
Downham Market
Lowestoft
Ely
Upware
Culford
Bury
Debenham
Snape
Orfordness
Woodbridge
Ipswich
Saffron Walden
Harwich

flexure ranges from Witham to Ipswich and Woodbridge to Snape and Lowestoft.

It would be difficult to presuppose any movement in plastic or semi-plastic matter having occurred without extensive compensations taking place in substance and form in and beyond the actual foci of movement. Consequently, in all changes of form of a dominant character which from one cause or another have been impressed upon the crustal or super-crustal zones, there will be found reduplications of such forms extending more or less parallel with their direction, but becoming less and less distinct as they proceed outward until dying out altogether, or becoming lost in nearer and, therefore, more influential zones of modification.

As the fulcrum of movement is approached, situated somewhere on the eastern side of the platform, or the western side of the plateau, an area of comparative quiescence is met with, beyond which movements increase in intensity and range the farther the observer proceeds from it.

The eastern section of the London platform, that is western Essex and northwestern Kent, and the eastern section of the plateau, in Suffolk, were the areas where the greatest extent of subsidence took place during Upper Cretaceous time, but northeastwards from Weeley, Harwich and Culford, an increase of subsidence occurs. The dip of the subsidence was not eastwards from off the Calvert-Bletchley line upon a gradually increasing slope after the tangential angle of strain is passed at Bedford, but upon a northeast dip requiring a northwest-southeast line as the fulcrum of movement.

Such direction corresponds roughly to a line already mentioned as a probable course of disturbance discernible in a more northern and older series from the earliest Trias period, viz., a line through Peterborough, Culford, Debenham and Orford Ness.

The whole swing of the east coast north of Orford is based upon an inclination from off this line. Such movements outwards from the summit of this course, depressing the region to the north of it, would mean a rise along the Kent-Cambridgeshire synclinal, with either attenuation of the Chalk from erosive agencies or default of deposition. That such a rise of the syncline may have taken place is exemplified by the thinning out of the Chalk in the boring at Saffron Walden, and to the denudation which has befallen it beyond and west of Cambridge.

The London platform regained a measure of stability during the laying down of the Norwich Chalk, but this was broken up

in the following Eocene period, and a fresh subsidence began, which was continued to the close of that period.

The eastern plateau partook of all these movements, but when stability had been broken up west of it in the platform, it apparently was elevated and exposed to denudation, for the Danian series, or Upper Chalk, has disappeared from the Norwich area. After the London platform was submerged under the Eocene sea, the eastern plateau was also depressed, but only along its border, including Lowestoft and Yarmouth, where the Reading Beds and London Clay have been found in borings.

At some time during the Miocene period, movement was renewed, raising the London platform and with it the Kent-Cambridgeshire syncline, whilst northeastward of the Culford-Weeley line depression set in, and the Crag beds of Pliocene time extended from Beaumont (near Weeley) to the Cromer region. The Kent-Cambridgeshire syncline had by this become more or less dynamically related to the London platform, and was comprehended as an integral part of it in all movements affecting it. The real focus of instability lay east of it in the eastern plateau.

Stratigraphical sequence comprehended in the anticlinal or axial form. The series of beds forming the cores and flanks of the ridge folds differ in different geological areas. In the Pennine Chain, for example, the visible fold is composed of Carboniferous Limestone, although it is practically certain that the protaxis itself is pre-Carboniferous, Cambrian or older.

In the Charnian axis the apical fold is pre-Cambrian, while the flank folds are Cambrian, Silurian and Carboniferous Limestone as proved in the visible outcrop of Charnwood Forest, in the boreholes about Market Bosworth, the Nuneaton anticline and the borings at Northampton. The stratigraphical sequence proved in the Wharfe Anticline comprehends Carboniferous Limestone, Millstone Grit and Magnesian Limestone, while the concealed section is composed of a discordant cover of Trias, Jurassic and Cretaceous series. The crystalline core upon which rest these sheets of sediment is probably Silurian (Upper and Lower) as met with at Kendal and in the Upper Ribble Valley.

On the northern section of the line at Crossness, Old Red Sandstone forms the deepest beds bored into under a cover of Upper Cretaceous and Tertiary, but at Cliffe farther east, the Silurian core is met with under a cover of Upper Cretaceous beds.

Sequent relation in direction and position of Petroleum Surface Indications with the position of visible or concealed Anticlines. The relation of surface escapes of oil in Britain to underground

structures has, so far as true geological correlation is concerned, never been adequately carried out. In order to determine this relationship, it has been necessary to examine the structure of the east coast of England as closely as the evidence available will permit. The space occupied thereby is perhaps out of all proportion to the rest of the questions which are the object of this paper. But these can only be adequately approached by the road of causes and effects.

In England, the occurrence of seepages have been regarded as erratic expressions of oil from Coal Measure sandstones, and in those places, such as Tregaron and Llanidloes, where no Coal Measures exist, interest in the question has not been sufficiently intense for any other practical theory to be constructed. Indeed, the whole question of oil in Britain has been treated as one of academic interest. The reasons for this is perhaps attributable to the importance of coal as a fuel, and its practical bearing upon the industries of the nation.

Oil, if present in great quantities and widespread, must occur in rocks of an age not hitherto supposed to contain it. No country has been bored so generally as Britain, and yet no country has, strictly speaking, been less tested in depth for liquid oil. And it is just at a depth below the objective of the coal miner that petroleum in this country must be looked for.

It is now possible to classify the indications of petroleum mentioned in the earlier part of this paper, by their relation to the lines of flexure defined. Those of the Derbyshire limestone district are directly upon the Pennine axis. The Southgate Colliery, Clowne, is on the northern flank of the Norton-Tuxford anticline. The Riddings Colliery is on the flank of a small irregular dome, with its longer axis parallel to the Pennine trend. Like the Barnsley Colliery and Ilkeston positions, the Kelham boring is not near any well-defined axis, but the anomalous sequence of beds found in the last may have some structural cause with which the discharge of oil is connected.

To the west of the Pennine Chain in Lancashire, petroleum escapes are met with at Atherton, Worsley, and Eccles on the flank of the anticline, and seem to be due to a series of subordinate folds lying on the northwest-southeast system of trend, but meeting the Pennine fold at a tangent. Fracturing should be the result with escapes of oil, just as we find occurs on the eastern flank.

The next series of oil escapes are found on the east of the depression, and correspond to a line drawn northwest along the

western escarpment of the Chalk in Lincolnshire. The most northerly is at Brigg, exactly on an east and west line of disturbance which is made apparent by the Secondary series being thrown into a convolution or ridge fold, and projected eastward beyond Barnetby as a long indent in the more or less uniform line of the Chalk escarpment. The whole Secondary series is involved in the movement: the Inferior Oolite is pushed eastwards, and a broad outcrop of the Great Oolite is pressed between this and the Oxford Clay. The narrowed outcrop of the Great Oolite is hardly discernible, and it appears at first as if the Oxford Clay had swelled out and overlapped it. The Oxford Clay, similarly, is thrust eastward, and causes the Kimmeridge Clay to be folded back along the edge of the Oxford Clay indent. Although it has been generally believed that the oil escapes at Brigg are attributable to oil expressed from Kimmeridge Shale, the position of Brigg on this visible line of movement is highly significant, and when further evidence is taken of a parallel fold to the Pennine Chain east of Brigg, the assumption of a deeper source for the oil escape than Kimmeridge Shale is strengthened.

Escapes of oil are reported at Market Rasen and Donington-on-Bain. Hereabouts the previously simple narrow outcrop of Neocomian separating the Chalk on the east from the Jurassic rocks on the west, becomes broad and complicated by outliers of Chalk and inliers or long tongues of Neocomian, due to undulations parallel or transverse to the Louth-Willoughby anticline. The long intrusion of Kimmeridge Clay east of Spilsby is one of these subordinate anticlines.

Horncastle lies on a transverse fold, apparently continued from the Castleton district through Tuxford and Lincoln. Its prolongation seems to pass the end of the chalk between the Spilsby and Louth anticlines, but there is chalk southeast of this at Skegness, reaching to 75 feet below sea level, a position which implies other flexure than the Louth anticline. Possibly, however, the Welland, or Bicester-Yaxley anticline may come in to accentuate the disturbance.

Across the Wharfe axis in the North Sea depression the position of oil escapes are equally suggestive. Two great flexures are discernible in this area, viz., the Middleton-Darlington-Stokesley-Scarborough fold parallel to the Wharfe, and belonging to the Charnian system of trends, a synclinal in the Palæozoic, but an anticlinal in the Secondary rocks, and the Cleveland uplift, of Caledonian trend, and probably posthumous. Both Kirkby Moor-

side and Pickering are stated to show signs of oil occurrences. These two places are situated westnorthwest-eastsoutheast of each other along the southern flank of the Darlington-Scarborough fold. Still further proof is forthcoming of the influence of this fold as the cause of oil occurrences at Filey. At Middlesbrough another oil escape has been observed in the angle between the Cleveland axis and the Middleton-Scarborough fold. It seems more probable, however, that it belongs to the latter.

Only four more visible occurrences of oil of any historical significance remain to be examined in the east of England, viz., at King's Lynn, Downham, Littleport and Ely. These escapes are found along the crown of the Ouse Valley fold, probably one of the great radicles of the northeast-southwest system.

The points where the escapes occur, although separated by variable distances from each other, are nevertheless just at those points which more or less conform to the meeting of the suspected Caledonian and Charnian system of foldings running through Norfolk.

Before tangible evidence was forthcoming of the presence of the Ouse Valley fold, it was considered probable that these indications arose from the Charnian fold alone. Since the mapping of the former structure has been effected (although there remains much to be done in this direction), this view as to the origin of the oil escapes is no longer tenable. It is definitely perceived that their position points to their coming from the Ouse Valley fold, or from those lines of disturbance where the two systems conflict with each other.

Besides the historical instances above enumerated, independent geological examination of the oil-bearing shales outcropping along the crown of the fold has been responsible for remarkable discoveries with regard to the nature and occurrence of oil in these beds. Not least in importance was the discovery that the shales contained oil of a dual character, that the greater part of the oil in the shales was free, and only required a low temperature (350° F.) for its extraction. In other words, it looks as if the oil comes off whenever its physical affinity for the surrounding media in which it is held is broken down.

Again, there is a progressive alteration of the oil as it ascends in the series of shale beds, being found lighter in gravity in the upper beds than in the lower. Likewise, the free oil, very low in specific gravity, is found in appreciable quantities in the sandstones capping the shale beds. Deep in the series, a three-feet seam of what appears to be manjak has been encountered, whilst, in the

course of the geological operations, the petroleum gas escaping in the shafts was so strong, that the men were unable to work in them.

All these acts united comprehend an argument so strongly in favour of deeper sources of free oil in this neighbourhood, that it is hardly possible to strengthen it by any external evidence whatsoever, but if this be required the relative position of underground structures to these escapes, and the finding of true petroleum in the Millstone Grit series at Kelham completes the edifice of substantive proof.

When it is observed that the Norfolk deposits of oil-shale containing free oil are of very great extent, comprehending hundreds or thousands of millions of tons, each ton of which may contain an average of 30 to 40 gallons of oil, and 75 per cent. of it in the form of free oil, which at one time or another must have as far as substantial evidence goes, been retained in underground structures adjacent to the field, an idea can be gained of the enormous bulk of petroleum which has already been absorbed into these overlying beds, and, as there is no visible evidence of fracturing or faulting upon any scale of sufficient magnitude to have completely dissipated the oil-contents with the production of large masses of bitumen, the assumption is alone possible that the oil absorbed in the overlying beds is of the nature of a vast seepage, and that there is still a bulk of petroleum in these underground structures commensurate with that which has already been absorbed by the overlying shale beds and sandstones of the Upper Oolite horizon.

The inevitable relationship exhibited between oil escapes and the underground anticlinal form on all occasions when present, is one of the most remarkable ruling signs in the whole sphere of oil research in Britain. It is so constant in sequence and design that one is obliged to consider it as a basic law in the system of underground connections, and to conclude that where such inevitable constancy is found ruling, the oil escapes cannot be erratic exudations of oil from shales on the surface, accidental, and having no continuity or significance, but they must be the outward and visible expressions of vast deposits of petroleum retained in long-buried geological structures, deposits which have not been dissipated throughout the ages.

Conclusion. One point of importance alone remains for discussion, and that is this: Are the oil-containing beds too remote for testing, or do they lie well within the level of economic drilling operations?

The maximum thicknesses of beds above Coal Measure rocks or

newer than them when absent, are given below in descending order as follows :

		Feet.		
1.	Chalk	1,350	...	Holderness.
2.	Upper Greensand ...	12	...	Near Aylesbury.
3.	Gault	245	...	Bulbourne and Tring.
4.	Neocomian, Lower Greensand, Speeton Clay, etc.	350	...	
5.	Purbeck beds	—	Represented by Speeton Series.	
6.	Portland beds			
7.	Kimmeridge Clay ...	500	..	Vale of Pickering.
8.	Coralline beds ...	380	...	Vale of Pickering.
9.	Kellaways Rock, Oxford Clay ...	500	...	Oxford and Fens.
10.	Cornbrash	25	...	Witney.
11.	Great Oolite	800	...	Cleveland.
12.	Inferior Oolite			
13.	Lias	1,100	...	Cleveland.
14.	Rhætic	65	...	South Scarle near Lincoln.
15.	Trias	1,950	...	Scunthorpe and Goole.
16.	Permian	540	...	Snaith (West Bank).
		7,817		

Such would be the depth to the top of the Carboniferous series or that portion remaining after denudation, were all the Permian and Secondary beds to develop a maximum thickness in one place, but these rocks vary in vertical measurement greatly and significantly when traced from district to district.

Professor Kendal holds the view that nowhere in the region under discussion, viz., from the Wharfe anticline to the edge of the Culford pre-Carboniferous outcrop, will more than half or two-thirds of the true thickness be found.

A study of the nearest boreholes will determine, as far as possible, the various thicknesses of overlying beds within the eastern depression. As a result of such study it is found that the probable thickness under West Norfolk is as follows:

Kimmeridge Clay	500 feet	
Oxford Clay	400	
Lower Oolites	120	(Crowland)
Lias	1,000	(Grantham)
Trias	1,200	(Newark)
To Carboniferous or older rock ...	3,220	

There is, therefore, no foundation for assuming that the formations in northwest Norfolk, separating the surface from the Carboniferous Limestone or other series, containing the oil sources which are supported by the older Palæozoic floor, are beyond reasonable drilling depth. All evidence, indirect or substantive, points to the oil being at accessible depth. The thickness of the oilsands or the beds containing oil of course cannot be even approximately measured, but from the enormous quantity of oil which has escaped into the oil-shale series of northwest Norfolk, the underground retaining structures must be of very considerable extent, and should still contain vast quantities of petroleum.

With regard to the more northern and western sections of the eastern depression, numerous boreholes have penetrated partly or entirely the Coal Measure overlie, and there is no apparent reason to believe that the oilsands where they are suspected to exist from the presence of oil escapes on the surface, are below depths accessible to the drill. The oilsands in the boring at Kelham were 13 feet thick, at a depth of 2,439 feet 2½ inches from the surface, and were believed by some observers who have examined the boring to be only the upper sands of a productive series of unknown thickness. There is, however, no sign in this neighbourhood or on either flank of the Pennine anticline, of such vast quantities of oil as are found absorbed in the oil-shale series of northwest Norfolk.

If the imperfect reading of the Geological Record in my hands can impress upon you the great importance of the subject, and that wider public beyond you, who will so impartially benefit by the demonstration and exploitation of oilfields in our midst, so that co-ordination of effort between corporations or individuals can be secured towards testing the English formations for petroleum, or in justifying the Government to treat the question as one of National importance and worthy of their best attention, then, and only then, will the initial effort so imperfectly exposed herein be adequately justified.

DISCUSSION.

The President, in opening the discussion, said he was sure the members would agree with him that the author had taken a considerable amount of trouble in preparing an excellent account of a subject of great importance. He had placed before the members

a large amount of carefully-selected evidence from existing geological records and some data concerning petroleum also presumably recorded somewhere. He hoped the author in his reply would be good enough to state the source of this information. The author had drawn a hypothetical picture as to the possibility of the occurrence of commercially valuable petroleum in England, and in bringing that matter forward had done a great service not only to the Institution but to the country in general. He hoped the paper would have the effect of stimulating others to carry still further the interesting work that the author had accomplished. It had frequently been his privilege from the chair to call upon the late President, Sir Boverton Redwood, to open the discussion on papers read before the Institution. He had the pleasure of doing so on the present occasion, and at the same time expressed the pleasure of the members at seeing Sir Boverton present again after his absence from the last meeting.

Sir Boverton Redwood, Bart., said that in his view it was scarcely possible to over-estimate the amount of patient, persistent and laborious research which had been necessary to enable the author to present the very remarkable paper to which the members had just listened, the first attempt, he believed, that had ever been made to put forward comprehensively views in relation to the occurrence of petroleum in England, a subject which nevertheless was obviously one of the highest national importance. He had been most favourably impressed, as no doubt the other members had, by the detached unemotional manner in which the author had given his address. He obviously had inoculated himself against oil fever, and when he compared this philosophic calm with the mental exaltation of the many Americans whom he met in the oilfields of the United States thirty or forty years ago, he realised that Dr. Forbes-Leslie was the right man for the members to take as their guide in dealing with the subject.

There had, however, within his personal experience, been some little local excitement in this country in connection with petroleum discoveries. Twenty-five years ago he was asked to investigate a sudden influx of petroleum into a water well at Ashwick Court, near Shepton Mallet in Somersetshire, the residence of a medical man. The well was the sole source of water supply to the house, which occupied an isolated position on high ground.

The narrative which he heard from the servants, on his arrival with the late Mr. Topley of the British Geological Survey, an old friend and highly-esteemed colleague of Mr. W. H. Dalton, was not altogether devoid of elements of romance. The statement was that

the cook had peeled the potatoes for the midday meal; put them into the saucepan and carried the saucepan into the scullery, a dimly lighted annexe to the kitchen, wherein was situated the pump over the well to which he had referred. She filled the saucepan in the customary way from the pump, returned to the kitchen, put the saucepan on the fire, and went about her other duties. Shortly afterwards the housemaid, coming into the kitchen, remarked what a strong smell of paraffin there was, and, proceeding to investigate the cause, went to the fire, and exclaimed to the cook, "Why, you have filled the saucepan with paraffin instead of water!" That led to the pump being put in action, and it was found that petroleum instead of water was obtained. The gardener was called in, and proceeded vigorously to apply himself to the pump-handle. Opportunely, at that moment the master of the house arrived on the scene, stopped the pumping of the oil to waste, sent the man down to the village for some empty barrels, and he (Sir Boverton) learnt that some dozen or more barrels had been filled before the supply was exhausted.

The publicity which was given to the occurrence led to his receiving a good many communications from people in different parts of the country. One he remembered in particular from a lady living in Ruabon, who complained that the water-well supplying her estate was frequently so contaminated with oil that it was quite impossible to make use of the water. Mr. Topley and he investigated that matter also, and found that undoubtedly very considerable quantities of oil periodically found their way into the well. The discovery at Kelham, referred to in considerable detail by the author, was a more recent occurrence of the same order. It was worthy of note, in connection with the question, that, according to Camden's *Britannia*, Pitchford, in Shropshire, took its name from the fact that there was a spring which had yielded—probably for hundreds of years—a certain amount of oil. He visited the spring some years ago, and was able to collect a quantity of inspissated petroleum from the surface. It was also on record that a hundred years ago, rock from the vicinity was distilled as a commercial operation, yielding a description of mineral oil, which was sold as "Betton's British Oil," as a cure for sprains and rheumatism. He only desired to say in conclusion that he shared very strongly the hope expressed by the author, and endorsed by the president, that this most instructive paper would stimulate action, official or otherwise, in the direction of a systematic investigation of the occurrence of petroleum in this country. If Dr. Forbes-Leslie's anticipations—which seemed to him to be well founded—

were even partially realised, it was quite obvious that not only would the author be compensated for the vast amount of labour which he had, for many years, given to the subject, but the Institution also would be entitled to credit for having been the means of putting forward the communication.

Mr. E. H. Cunningham Craig agreed with Sir Boverton Redwood's statement that the great value of the paper was that it would make people think about oil in this country. Instead of denying its existence they would inquire into the evidence on the subject. The very interesting and carefully worked out tectonics given would give matter for lengthy discussion, to which however a map was essential in order to follow the author's exhaustive analysis of the lines of tectonic movement. The paper was a revolutionary one; the author had come to the subject with an absolutely free mind, not tied down to any of the fetishes of the Geological Survey, their theories and fixed ideas about Great Britain, and had gone to the root of the matter in dealing at once with the tectonics of the subject, which he had explained as simply as was possible. All geologists had learnt the tectonics of Great Britain after a fashion, but the author had gone into very much greater detail, and had stated in the paper much that was not contained in any textbook, and had not been explained by any professor in the country.

He gathered that Dr. Forbes-Leslie's chief point was that there was one great source of oil in this country, namely, in the Carboniferous formation, and that what oil and oil-shales they had in the Jurassics was accidental. That was a point which might be discussed at great length. There was no doubt whatever that in Derbyshire, in concealed parts of Nottinghamshire, in Staffordshire and in other parts of the country, wherever the Carboniferous rocks had been folded into really good anticlines, and wherever some of the beds containing the raw material to form oil had been preserved in those anticlines, there was evidence of oil. It was quite evident to him, and probably also to everyone present, after hearing the paper, that if there existed in Great Britain Carboniferous strata, concealed under Jurassic formations eminently capable of keeping down and sealing up petroleum, and if these Carboniferous rock formations were in anticlinal form and well sealed, there would be oil present. But the question was, Were those evidences that they obtained in the Jurassics evidences of filtered oils from a lower source, or did they belong indigenously to the Jurassics? And there it was necessary to have some evidence as to the oils themselves. If those oils had come up from the Carboniferous rocks below, one would expect to find them showing all the characteristics

of very highly filtered oils, and that, so far as he knew, was not the case.

He was inclined to think that there were two sources at least of oil in this country, and possibly a third. One existed in the Carboniferous series, and had perhaps been mostly lost, as the Carboniferous rocks were present chiefly in basins, and the anticlinal crests had been removed; and there was another in some of the Jurassic strata.

In regard to one point, he was absolutely in agreement with the author, viz., that if any good Carboniferous anticlines had been preserved and concealed, there was oil in them yet, and that it could be obtained by drilling.

Mr. T. Ford (F.G.S., visitor) quite agreed with the general conclusions of the author's excellent paper. He was personally acquainted with several of the regions dealt with—the Leicester district, the Lincolnshire district between Donington and Market Rasen, the Retford and the Kelham districts—and the author's conclusions in regard to those regions were quite in accord with his own observations, preparing him to accept the wider conclusions of the paper. In the Kelham boring, put down under the speaker's superintendence, the oil was discovered somewhat accidentally, as coal was the object of search, and the bore had passed quite through the Coal Measures into the Millstone Grit, in which a peculiar sandstone occurred, unlike any he had previously met in that series. In washing the core, in order to examine it properly, oil immediately began to ooze out, and he proceeded with the rest of the boring with additional interest and caution. For about 15 ft. the drill passed through loose, brownish sandstone, and oil flowed up to the surface each time the rods were withdrawn. When the boring had got through the grits on to the limestone—which, by the way, was full of corals—the boring was stopped, and the hole left open for about eleven months, during the whole of which time oil continued to flow up continuously and regularly. It was a remarkable thing that oil should flow up at all against such a hydrostatic pressure as was represented by the column of water in the borehole. Oil experts generally took very elaborate precautions to prevent water getting into an oil boring; but in this case the boring was full of water, and, therefore, the fact of oil exuding continuously from the boring, under the pressure due to the head of water, was more remarkable still, and was evidence that there must be very considerable pressure behind it.

In the Millstone Grit series there was first of all a sand producing highly saline water; then a bed of fireclay, some shale and then

the petroliferous sandstone; the bed of shale immediately underneath this gave a certain percentage of oil on distillation, so that the whole arrangement of the strata was a true petroliferous one. There was either a fold in the immediate vicinity, or a fault, or an eastward rise of the measures, because the position at which the Millstone Grits were struck at Kelham was considerably above that of the series some few miles westward. He therefore thought the views of the author were quite in agreement with the actual facts of the case, pointing to the probability of deep-seated free oil here and in the eastern counties. Surface indications of oil, as at Alfreton and Kelham, should be taken particular notice of. He believed that the eastern counties contained quite a large oilfield, and that future borings would prove such to exist along the Trent Valley.

The Kelham boring had penetrated virgin ground, to a deeper horizon than had been expected as accessible, and had discovered a source of mineral wealth wholly unforeseen. The results were of sufficient national interest to justify further exploration and research, and every encouragement should be given to test thoroughly the extent and richness of this petroliferous ground.

The thanks of the meeting and indeed of the Nation were due to Dr. Forbes-Leslie for the extensive research work which must have been entailed upon him in compiling such a valuable record of data as was contained in the paper just read, and which might well become historic.

Dr. Henderson said the paper was rather inconvenient for immediate discussion, owing to the impossibility of digesting the large array of facts which it had presented at such short notice. Without a map members were absolutely at a loss when reading the paper. He hoped that the author would attach to the paper when printed a map showing the lines of structure, and the occurrence of the various oil seepages mentioned. Of these it would be very interesting if a list were given, containing particulars of the type of oil and analyses, as a guide in forming an opinion on the subject, essential to intelligent criticism.

He noticed that the oil obtained from the borehole at Newark was very heavy. In contrast to the observations of Mr. Cunningham Craig, he had usually found that oils which had migrated, particularly through fractures in the shale, were thicker and heavier than the original oils. In the Appalachian fields, as a general rule the specific gravity of the paraffin-base oils decreased with depth. On the other hand, where the oil had in its migration been subjected to natural filtration, small accumulations of very light oil resulted. The distinction was between oil escaping through fissures, to which

he believed the author had referred, and by filtration, the physical and chemical effects of the two methods of migration differing considerably. Possibly the oil at Kelham might come through fissures from some deeper-seated petroliferous horizon, if such existed. The belief that the Lower Carboniferous measures were or had probably been the home of large deposits of petroleum seemed justified by evidence long since available, and from the excellent summary presented in the paper. At the same time there appeared in the data furnished by the author in this and his previous paper, little reason for assuming that the petroleum found, free or otherwise, in the Norfolk shales, had a deep-seated origin. The available evidence, moreover, was too meagre a basis for calculations as to the age and depth of the source hypothecated. Further, it was clear that until either the possessors of mineral rights realised the need of the most liberal treatment in the way of extended leases with low royalties and easy conditions of tenure to those willing to undertake the hazardous task of exploratory drilling, or a drastic modification of legal enactments was effected, there was little likelihood of adequate financial support for extensive and deep drilling. He welcomed the paper most heartily, because it drew attention to the crying need of research in this country in the direction indicated.

Mr. W. H. Dalton said there was every reason to believe that the Kelham boring traversed a large fault, which, if faults could feed oil upward, might have been the source of that oil.

Mr. Hardy Manfield said that, in view of the very great importance of the announcement made by the author that free oil had been seen exuding from the shales in Norfolk, he was sure some of the members of the Institution would welcome the opportunity of visiting the spot, if the author could arrange for them to do so.

Dr. Forbes-Leslie, in reply, said the sources of the information contained in the paper might be placed in three classes. In the first, he had taken data freely from various authors who had dealt with the question of escapes of oil in England, chiefly in the Proceedings of the various Institutions. In the second class, he had, with regard to the Norfolk area, his own field-notes. Lastly, he was greatly indebted to Mr. Ford for information supplied with regard to the oilsands at Kelham. He had much wished to prepare a large map for exhibition, but time and work prevented him doing so. He quite endorsed Dr. Henderson's suggestion that, when the paper was printed in the *Journal*, there should accompany it a map with the tectonic lines, in order to show their relation to surface escapes of petroleum, and he would add the analysis of such oils where it was

possible to obtain them. He thanked the President, Sir Boverton Redwood and Mr. Cunningham Craig for their very kind remarks. He was exceedingly pleased that Mr. Cunningham Craig at one point endorsed his view that there were sources of oil concealed in the Carboniferous formation, and it was quite possible that in certain parts of the eastern depression Carboniferous rocks in anticlinal form might be found concealed by overlying Jurassic strata. It was quite possible, however, that there was another source of oil in Britain, viz., indigenous to the Jurassic, but he was afraid that the solution of the problem was rather distant.

The sole object of his paper had been to introduce a new interest into what had been previously an academic question, the possibility of an oilfield in England; and it was quite possible that an economic source of oil in this country would be found before long. Geologists could proffer working hypotheses, balancing indirect against direct evidence, and deducing conclusions, but the final proof must almost always remain with the drill.

Finally, he desired to thank Mr. Dalton for his kindness in revising the paper, and suggesting many points of which he was not previously aware; and he also desired to thank the members for the patient manner in which they had listened to such a lot of dry detail.

On the motion of **The President**, a hearty vote of thanks was accorded to Dr. Forbes-Leslie for his very valuable paper.

Subsequently **Mr. W. H. Dalton** wrote as follows:—

The author's main thesis, that all oil-occurrences in England are derivative from some common source in deep-seated strata, is not likely to meet with general acceptance. It is more in accordance with the principle of least violation of probability to suppose that Nature, always making petroleum somewhere, has casually left some of it under protection in its original positions, and that migration has rarely occurred, except for short distances along the course of beds of like nature.

Since the Scotch kerogen has been shown to have been once petroleum, subject to concentration by anticlinal flexure before losing its fluidity, the evidence of similar disturbance in English shalefields may eventually prove of importance,but the chief value of the masterly summary presented of the tectonic structure of Eastern England lies in relation, not to imagined oil pools, but to concealed coalfields, known to extend into western Lincolnshire and southern Nottinghamshire, though limited to west, south and east by the uprise of earlier rocks.